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BUREAU OF WATER AND WASTEWATER

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High Level Sewershed Evaluation Study Plan
Project 1028

December 18, 2009

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HIGH LEVEL SEWERSHED STUDY AND PLAN
PROJECT 1028
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EXECUTIVE SUMMARY

On September 30, 2002, the City of Baltimore (City) entered into a Consent Decree (CD) with the United States Environmental Protection Agency (EPA), the State of Maryland Department of the Environment (MDE) and the Department of Justice (DOJ). The objective of Paragraph 9 of the CD is to complete a series of "Collection System Evaluation and Sewershed Plans". This Sewershed Study and Plan details the evaluation of the High Level Sewershed.

The High Level Sewershed (HLSS) is one of eight individual sewersheds located within the City of Baltimore. The sewershed includes approximately 924,416 linear feet (LF) of gravity sewer ranging in size from 8- to 100 inches in diameter; approximately 5,030 Baltimore City maintained manholes; 270 LF single barrel 20-inch siphon beneath highway US 40 and the 950 LF triple barrel 42-, 42- and 36-inch High Level Interceptor Siphon that passes over the Jones Falls culvert and underneath Interstate 83. The HLSS does not contain sanitary sewer pump stations. The Jones Falls Pump Station force main/pressure sewer and several of its abandoned predecessors cross the HLSS but are not evaluated as part of the HLSS study.

The collection system is comprised of two primary interceptor systems: the Gwynns Run Interceptor (GRI) and the High Level Interceptor (HLI). The GRI begins in the northern reaches of the sewershed near Pimlico Racetrack and runs south to the High Level Interceptor. The GRI Interceptor runs approximately parallel to the Gwynns Run tributary; a small stream that drains into the Gwynns Falls. Capacity issues in the GRI resulted in the Sanitary Contract (SC) 812 project a Consent Decree Paragraph 8 project with the intent to relieve adjacent neighborhoods and environmental areas of chronic sanitary sewer overflows (SSO's).

The HLI starts as a 33-inch sewer at the western border with the Gwynns Falls Sewershed. The large size allows significant flows to be diverted from the Gwynns Falls Sewershed to the HLI via the Baltimore Street Diversion in emergency situations. The HLI continues East along the southern border of the HLSS incrementally growing in diameter as more sewage flows are collected. The HLI passes through the valley created by the Jones Falls using the aforementioned HLI triple barrel siphon. As the HLI continues East through the HLSS, the HLI collects sewage from the Lower Jones Falls Interceptor, Greenmount Interceptor, the Jones Falls Pump Station force main discharge and the 99-inch Eastern Avenue Pump Station discharge before arriving at the border with the Outfall Sewershed. All sewage from the HLSS is eventually conveyed to the Back River Waste Water Treatment Plant (WWTP) for processing.

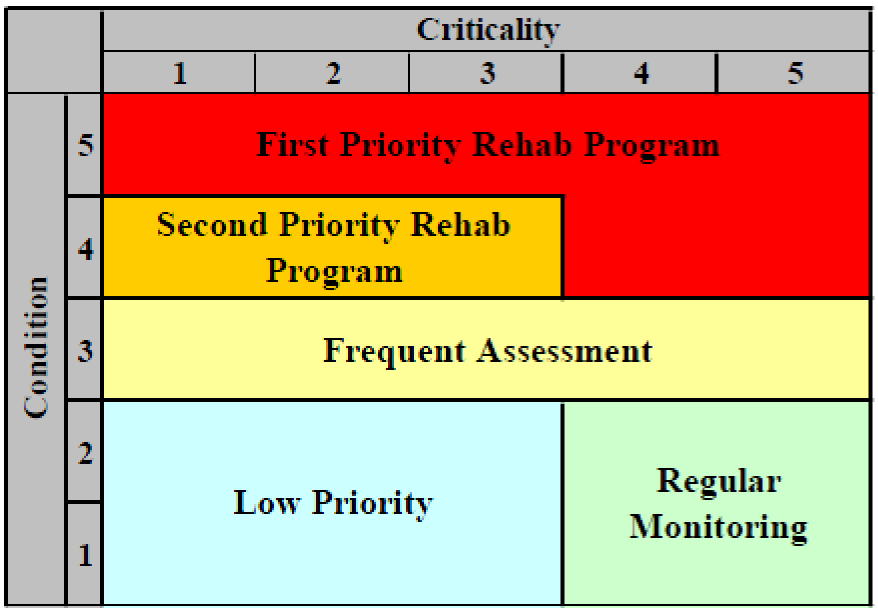
In accordance with the CD, the following items have been completed for the High Level Sewershed Study and Plan:

- Evaluated the effectiveness of the construction projects completed pursuant to Paragraph 8 of the CD using rainfall and flow monitoring data, as well as the hydraulic model developed in accordance with Paragraph 12 of the CD. It is the conclusion of this report that the Paragraph 8 projects have been effective in reducing the frequency and volumes of Sanitary Sewer Overflows (SSO's) in the sewershed.
- Presented the results of the rainfall and flow monitoring, as well as smoke and dyed-water testing, conducted in the sewershed.
- Identified all deficiencies discovered during the collection system inspections, which included inspection of all gravity sewers having a diameter of eight inches or greater using closed circuit television (CCTV) inspection and complete the inspection of all manholes and other appurtenances.
- Identified all rehabilitation and other corrective actions taken, or proposed to be taken, to address the deficiencies identified during the evaluation of the sewershed.
- Described the decision-making criteria used to select future corrective action.
- Proposed a plan and schedule for future evaluation of the collection system within the sewershed.
- Proposed a plan and schedule for implementing rehabilitation and other corrective actions determined necessary either to correct deficiencies identified during the collection system evaluation or to ensure operation of the collection system without causing or contributing to an SSO.
- Proposed a plan and schedule for eliminating those physical connections between the sanitary sewer collection system and the storm water collection system.
- Determined the range of storm events for which the collection system in its existing condition can convey peak flows without the occurrence of SSO's.
- Predictably determined the range of storm events for which the collection system will be able to convey peak flows without the occurrence of SSO's assuming completion of the Paragraph 8 construction projects and completion of the proposed rehabilitation and other corrective action projects recommended in this Sewershed Plan.
- Certified the Geographic Information System (GIS) described in Paragraph 14 of the CD.

As required by the CD, the Sewershed Plan identifies specific improvements or other corrective actions needed to; address deficiencies and aid in reducing rainfall dependent inflow and infiltration (RDII) contributing to SSO's, address deficiencies identified during the hydraulic analyses, and address other deficiencies that contribute to SSO's.

As part of the Sewershed Study, the City developed a condition and criticality protocol that provides the framework for a rehabilitation strategy based on criticality (consequence of failure) and condition (probability of failure) rating of 1 through 5. Assets whose failure can impact the community or environment and whose condition is the poorest received a higher rating and will receive attention sooner. Assets that receive a lower rating will receive some level of regular monitoring but no immediate action or rehabilitation. Five levels of prioritization were developed based on the combination of condition and criticality as shown in the following matrix:

Condition/Criticality Matrix



Prioritization of asset rehabilitation projects and other corrective actions was developed with consideration that all proposed improvements required to eliminate SSO's must be completed before January 1, 2016, as stipulated by the CD. The proposed improvements include elimination of identified SSO structures, rehabilitation of "First and Second Priority Rehabilitation Program" manholes and sanitary sewers, and required hydraulic improvements. The proposed improvement projects and the estimated costs to compete these repairs are summarized in the table on the following page.

Table ES-1: Proposed Improvement Projects Summary (Cost in Millions of 2008 Dollars)

First and Second Priority Sewer Rehabilitation		
Rehabilitation Item	**Length/Count**	**Est. Cost**
Manhole Rehabilitation/Replacement	622	$2,313,000
Cured-In-Place-Pipe Lining	67,016	$3,780,000
Sewer Point Repair (8"-+54" Repair)	5,308	$3,138,000
Sewer Point Repair and Cured-In-Place-Pipe Lining	44/1,069	$64,000
Sub-Total Estimated Cost:		$9,295,000
Sewer - Hydraulic Improvements		
Rehabilitation Item	**Length/Count**	**Est. Cost**
Heavy Sewer Cleaning 80"-100"	5,781 Tons	$2,891,000
8-Inch - 10-Inch Cured-In-Place-Pipe Lining	42,900 LF	$2,000,000
New 15-Inch & 30-Inch Relief Sewer Pipe	7,600 LF	$6,498,000
Manhole New/ Rehabilitation/Replacement	200	$744,000
Temporary Sewage Storage	450,000 gallons	$2,700,000
Sub-Total Estimated Cost:		$14,833,000
Total Eng. Design, Construction Mgmt, Inspection, Post Engineering Services (42%)		$10,172,000
Total Estimated Cost:		**$34,262,000**

The manholes and sewers that received higher condition and criticality rating scores were recommended for inclusion on the First and Second Priority corrective action plan.

The recommended hydraulic improvements include:

- Heavy clean the High Level Interceptor East of the High Level Interceptor Siphon.
- Construct a 2,800 LF 15-inch relief sewer in the Liberty Heights area.

- Construct an extension to the Paragraph 8 project SC 812 downstream to the High Level Interceptor.
- In the Upper Gwynns Run Region, perform an extensive inflow and infiltration (I/I) reduction program installing approximately 63,000 L.F. of CIPP pipe liner and repairing over 170 manholes. In addition, 450,000 gallons of temporary wastewater storage and a 2,400 LF 15-inch relief sewer are recommended to mitigate SSO's caused by a 2-year storm event.
- The High Level Interceptor Siphon contains significant accumulations of sediment and debris; however, according to model simulations, this condition is NOT the cause of SSO's for 2, 5, and 10 year storm events. Therefore, no immediate action on the HLI siphon is required.
- Sealing manhole S37CC_034MH lid to prevent the overflow of approximately 9,000 gallons of sewage. This manhole is the discharge chamber for the High Level Interceptor Siphon. The cost is insignificant and is not included as a line item in any of the cost tables in this document.

It should be noted that the interrelationship between the City's Sewersheds, known as boundary conditions, must be carefully considered before significant hydraulic repairs are completed. Six sewersheds are connected and hydraulically interdependent, creating "boundary" conditions that must be defined and considered for hydraulic modeling. The City is developing a system-wide model that will be refined and improved as the individual sewershed studies complete calibration of their respective models. This Plan provides recommended improvements that should be implemented by the City in accordance with the schedule provided. However, the Plan should not be considered final and may require amendment once the system-wide hydraulic model is completed and simulations are performed.

As required by Paragraph 9.C.xii of the CD, the City will also implement several continuous data collection programs in order to assess the effectiveness of the rehabilitation and other operation and maintenance enhancement efforts within the sewershed. These programs will be comprehensive, system-wide initiatives that will include a long-term flow monitoring plan, a sewer cleaning program, CCTV and manhole inspection programs and root and grease control programs.

1.0 PROJECT DESCRIPTION

1.1 Project Background

On September 30, 2002, the City of Baltimore entered into a Consent Decree (CD) with the United States Environmental Protection Agency (EPA), the State of Maryland Department of the Environment (MDE). The objective of Paragraph 9 of the CD was to complete a series of "Collection System Evaluation and Sewershed Plans". This Sewershed Study and Plan details the evaluation of the High Level Sewershed, one of eight Baltimore City Sewersheds.

The High Level Sewershed Study and Plan, Project No. 1028 generally consists of inspection and characterization of the sewage collection system. Project No. 1028 consists of a wide range of activities as defined by the CD. These include flow monitoring; collection of rainfall data; manhole inspection; closed circuit television (CCTV) video inspection; smoke testing; dyed-water testing; updates to the City's GIS based sewer mapping system; analysis of complaint data; projections of current and future base sanitary flow (dry weather); preparation; calibration and validation of a hydraulic model; identification of critical sewer system components; condition assessment and criticality rating; formulation of a long term rehabilitation and corrective action plan; preparation of cost estimates and preparation of the sewershed plan. In May 2005 the City of Baltimore contracted with ADS/JMT a Joint Venture to complete this work.

The study area for the High Level Sewershed includes approximately 925,000 linear feet (LF) of gravity sewer ranging in size from 8- to 100-inches in diameter; approximately 5,030 City of Baltimore maintained manholes and 2 sewer siphons.

The sewershed study and plan elements are defined in the CD Paragraph 9.C as summarized below:

- An evaluation of the effectiveness of completed and proposed projects using rainfall and flow monitoring data and the hydraulic model
- Identification of deficiencies discovered during inspections
- Identification of rehabilitation and other corrective actions taken to address deficiencies
- Identification of rehabilitation and other corrective actions proposed to be taken
- Description of decision making criteria for selection of future corrective action
- Plan and schedule for implementation of rehabilitation and other corrective action found necessary to correct deficiencies
- Preparation of a prioritization scheme applied to rehabilitation projects

- Preparation of cost estimate for proposed rehabilitation and other corrective action
- Preparation of a plan and schedule for eliminating physical connections between sanitary sewer and storm drains
- Determination of range of storm events for which existing collection system can convey peak flows without occurrence of sanitary sewer overflows (SSOs)
- Identification of model components that have the potential to cause or contribute to overflows
- Determination of the range of storm events for which peak flows can be conveyed without occurrence of SSOs once the recommended construction projects are in place
- Presentation of the results of rainfall and flow monitoring conducted in the sewershed
- Description of the quality assurance and quality control analyses performed for data collected
- Description of the smoke and dye testing performed
- Quantification of inflow and infiltration (I/I) and identification of sources of the I/I
- Description of additional data collection activities that will continue after completion of rehabilitation and corrective action
- Certification that the GIS system is functional in accordance with Paragraph 14.B of the CD

The content and structure of this Sewershed Study Report have been established to address each of the sewershed study and plan elements required under the CD.

1.2 Sewershed History/Previous Studies

The High Level Sewershed encompasses a wealth of history which can be seen in its fifty-two neighborhoods, transport system and various places of interest. Below the history of the Metro Subway, Interstate 170 and the Ashburton Filtration Plant are highlighted.

A. Transportation: Metro Subway

The Metro Subway currently provides transportation for residents living within neighborhoods found in the HLSS. In 1966, the original plans for the Metro Subway included having six transit lines radially from the City. However, due to overwhelming construction costs, the number of transit lines was reduced to one. The service operates on the green line from Metro Center at Owings Mills in the North West to the Johns Hopkins Hospital in the North East.

B. I-170

A plan was developed in the 1970s to connect Interstate 70 (I-70) to other Baltimore freeways. This connection was signed as Interstate 170 and was to extend beyond I-70's current terminus through Leakin and Gwynns Falls Park, meet Hilton Parkway, run between Route 40 (Franklin Street Westbound and Mulberry Street East bound) and eventually end at I-95 near Caton Avenue. However, only a small part of I-170 was actually constructed in 1976. This recessed 1.5 mile section of I-170 has since been dubbed the 'Highway to Nowhere'. A 20-inch siphon was constructed beneath this highway to serve HL 15, 16 and 17.

C. Ashburton Filtration Plant

Ashburton Filtration Plant is located on Druid Park Drive within the sewershed and is the largest wastewater discharger for the HLSS sanitary sewer system. The plant was placed into service in 1956 and has a capacity of 165 MGD. The plant includes four flocculators, four sedimentation basins, and 20 rapid sand filters. Raw water supply for this plant is obtained from Liberty Reservoir. The Ashburton Filtration Plant supplies water to the Second Zone(parts of Baltimore City and Baltimore County and Anne Arundel County) by gravity, and to the Third (northeastern part of Baltimore City), Fourth (Towson, Pikesville and Catonsville), and Fifth (Reisterstown and Pot spring) Zones by pumping.

D. Summary

The High Level Sewershed encompasses a wealth of history which can be seen in its neighborhoods, transport system and various places of interest. Many studies have been performed on the Sewershed and the wider City by multiple engineering consultants. The focus of the studies ranges from system-wide studies to hydraulic evaluation projects of specific sections of the collection system and span from the 1980s to present day. Where available, these studies were reviewed and considered in the preparation of this plan.

1.3 Purpose of Sewershed Study

The High Level Sewershed study assists in Baltimore's compliance with the Clean Water Act and Title 9, Subtitle 3 of the Environment Article, Annotated Code of Maryland and the regulations promulgated thereunder, and all terms and conditions of the Back River and the Patapsco NPDES Permits. SSOs and dry weather overflows have been evaluated for elimination in the High Level Sewershed collection system through development and implementation of the measures set forth in Paragraphs 8 through 15 of the CD. Construction projects 23 and 24 as identified in Appendix D of the CD have been completed. All but six of the SSO structures listed in Appendix C have been eliminated. Illegal stormwater or sewer connections are identified for elimination. Potential RDII sources from privately owned customer service laterals have been identified through an extensive smoke and dyed water testing program. Baltimore's GIS has been updated to be accurate, fully functional, and capable of displaying the information described in Paragraph 14.B.i through iv of the CD.

1.4 Description of the Sewershed and Sub-Basins

The High Level Sewershed is one of eight individual sewersheds located within the City. The HLSS includes a drainage area of approximately 7.2 square miles served by separate storm and sanitary sewers. The majority of HLSS drainage area is residential, with a total population of about 100,000. High Level Sewershed includes approximately 925,000 linear feet (LF) of gravity sewer ranging in size from 8- to 100-inches in diameter; approximately 5,030 Baltimore City maintained manholes and two inverted sewer siphons. The sanitary sewer system has two major interceptors, the Gwynns Run Interceptor (GRI) that collects flows from the northwest portion of HLSS area, and High Level Interceptor (HLI) that serves the southern portion of the drainage area.

Wastewater from Northwest portion of the HLSS drainage area is collected by the Gwynns Run Interceptor (GRI), which in turn, joins the larger High Level Interceptor (HLI) at the south end of the GRI. The HLI runs from west to east receiving flow contributions from the HLSS in the upstream reach, and from the Jones Falls and Low Level Sewersheds in the downstream reaches. The HLI joins the Outfall Interceptor at the beginning of Outfall Sewershed, and the Outfall Interceptor eventually conveys flow to the Back River Wastewater Treatment Plant (WWTP) for treatment. There are no permanent pump stations within the HLSS service area.

The HLSS interacts with a number of other sewersheds, which impacts the hydraulic conditions in the collection system especially during moderate or large rain events.

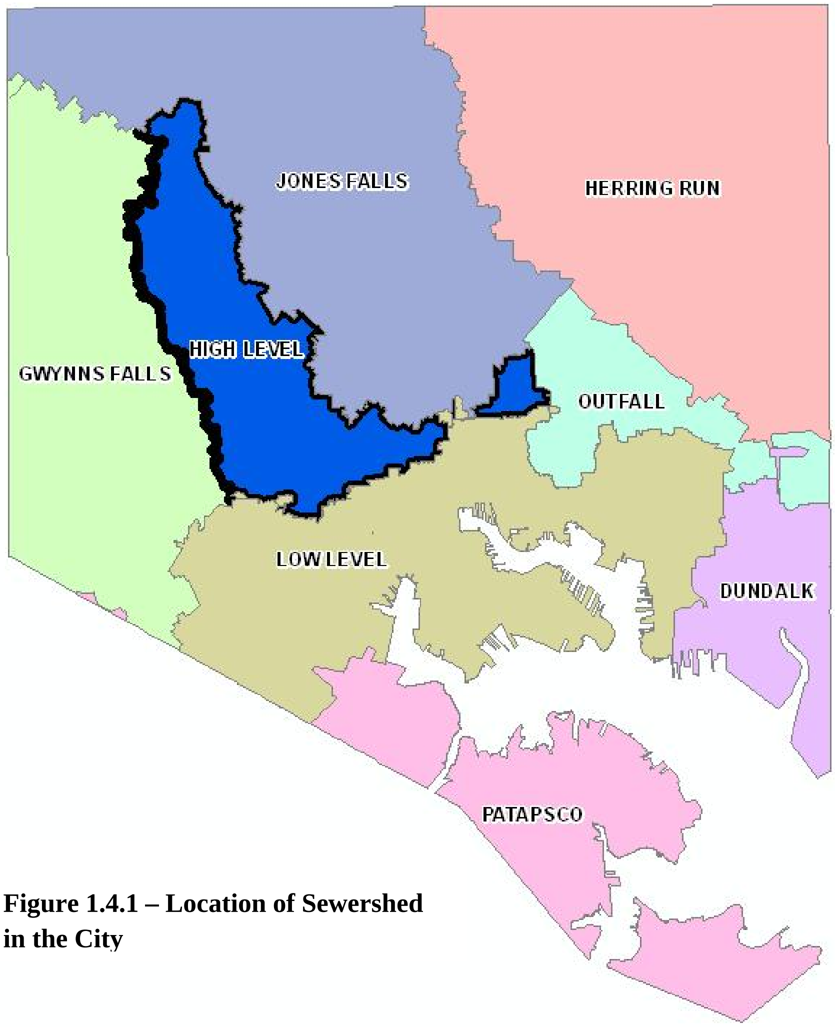


Figure 1.4.1 – Location of Sewershed in the City

The High Level Sewershed has been sub-divided into four different regions. The boundaries for these subdivisions are depicted in Map 1.5.1. Brief descriptions of each of the region and the major region interceptors located within the City's portion of the High Level Sewershed are provided in the following paragraphs.

The Upper Gwynns Run Region is bordered by Northern Parkway in the north, Garrison Boulevard in the West, Roland View Avenue in the East and Liberty Heights avenue in the South is served by the Gwynns Run Interceptor. The length of this segment of the interceptor is 14,245 LF with pipe sizes ranging from 11.5 to 30 inches. The total area of the Upper Gwynns Run is 0.3 square miles.

The West Baltimore Region starts just south of the Liberty Heights Avenue and extends between Garrison Boulevard and Roslyn Street in the west, North Bentalou Street in the East and Ellicott Dwy. in the south. The Gwynns Run Interceptor serves 0.2 square miles of West Baltimore above West Baltimore Street. This section of the Gwynns Run Interceptor has a length of 14,498 LF with pipe size ranging from 18-42" inches. The High Level Interceptor serves the area of West Baltimore between West Baltimore Street in the north and Ellicott Dwy. in the south. The length of this segment of the High Level Interceptor is 19,118 LF and consists of pipe sizes from 33-inches to 82-inches.

High Level Siphon Region serves the area of the High Level Sewershed bordered between Guilford Avenue on the West and just west of Homewood Street on the East and running along Eager Street. The High Level Interceptor is 1,502 LF in length with approximately 950 LF comprised of the High Level Interceptor Siphon. The High Level Interceptor ranges from 82-inches to 100-inches in diameter and the Siphon is comprised of three barrels ranging from 36-inches to 42-inches in diameter.

The 0.1 square mile Eastern High Level Interceptor Region begins just west of Homewood and ending just west of Wolfe Street on the East, with the northernmost and southernmost borders defined roughly by East North Avenue and Eager Street respectively. The length of the High Level Interceptor running through this area is 4,517 LF of pipe size ranging from 100-inches to 144-inches.

Within each of the described regions, there is a further division to the Sewershed Service Area (SSA) level as will be seen in Section 5, Hydraulic Modeling. Flow inputs for the hydraulic model are developed at the SSA level.

2.0 Effectiveness of Paragraph 8 Construction Projects

A series of construction projects, referred to as Paragraph 8 projects, were completed within the High Level Sewershed. The purpose of these projects is to reduce the frequency and volumes of SSOs. The Paragraph 8 construction project locations are shown on Map 2.0.1.

2.1 Engineered SSO Locations

A total of 13 known engineered SSO structures were identified in the High Level Sewershed at the time the Consent Decree was signed:

SSO#55	SSO#56	SSO#57	SSO#60	SSO#63	SSO#103
SSO#106	SSO#107	SSO#126	SSO#127	SSO#128	SSO#130
SSO#131					

These structures were designed to relief the collection system in the event of surcharge caused by hydraulic capacity limitations. Figure 2.1.1 below shows the location of these thirteen engineered SSO structures in the High Level Sewershed.

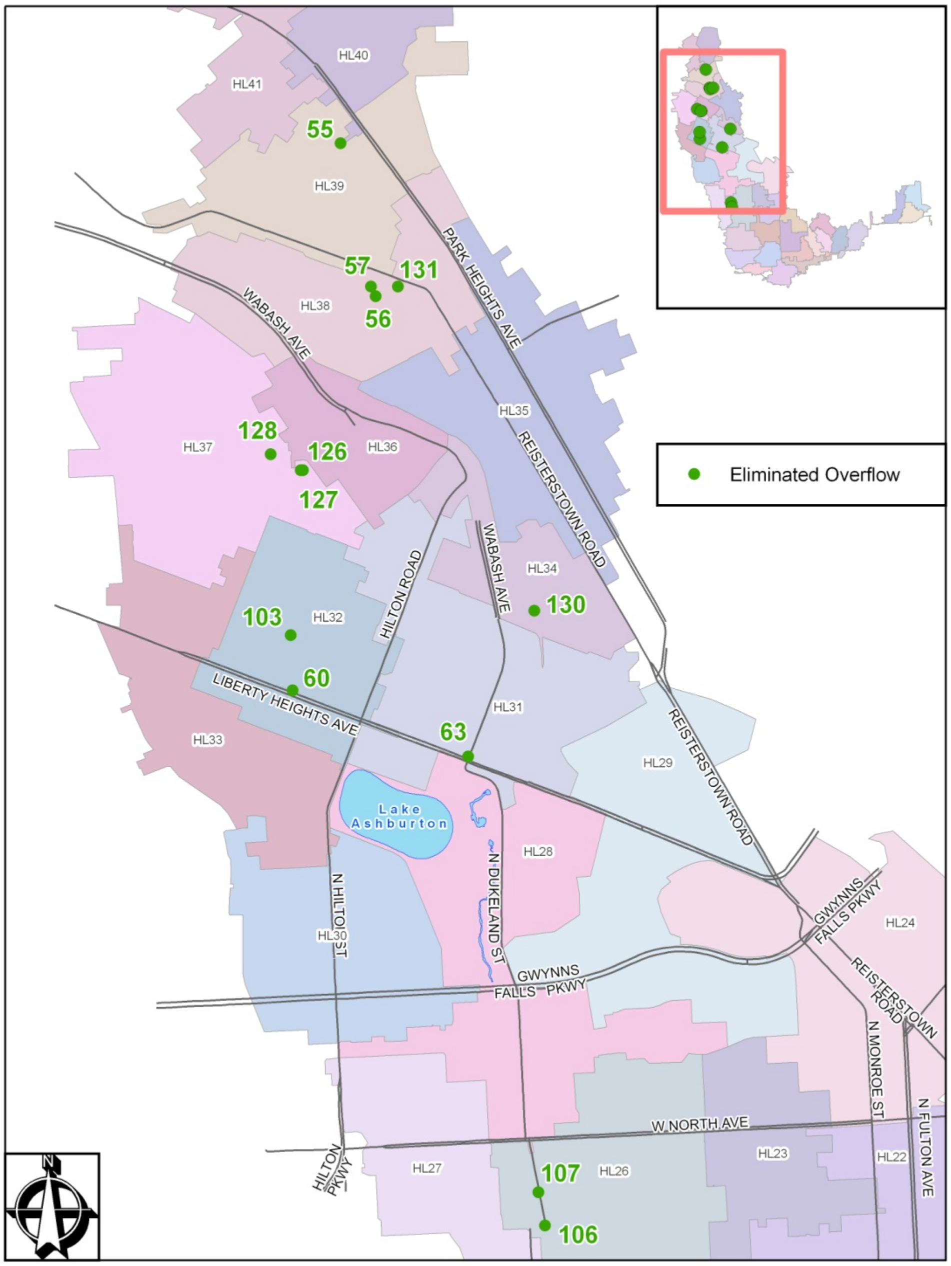


Figure 2.1.1 – Location of Engineered SSOs in the High Level Sewershed

2.2 Construction Projects

A listing and brief descriptions of the Paragraph 8 projects are presented in Table 2.2.1, all of which have been represented in the hydraulic model under baseline conditions.

Table 2.2.1 – Paragraph 8 Projects in the High Level Sewershed

Sanitary Contracts	Project	Description	Const. Complete	SSO Elimination	SSOs Eliminated
SC 812	Gwynns Run Interceptor	Improvements to Gwynns Run Interceptor	02/15/07	06/30/07	106,107, 130
SC 807	Gwynns Run System Imrpovements	Assess hydraulics and design improvements to areas adjacent to overflows	12/09/04	06/30/07	55, 56, 57, 60, 63,103, 126, 127, 128, 131

2.3 Pre- and Post- Construction Flow Monitoring

Following the signing of the CD in September 2002, the City of Baltimore began implementing a flow monitoring program in the Spring of 2003 to measure the flow at the engineered SSO locations throughout the City. Except for SSO #130, by the time the flow monitors were installed in the engineered SSO structure projects SC-812 and SC-807 had been completed. In the case of SSO#130, there was no post construction flow monitoring as SSO #130 was eliminated during construction. Therefore, because of the lack of either pre- or post-construction flow monitoring it is not possible to assess the effectiveness of the Paragraph 8 projects with flow data.

2.4 Hydraulic Model Simulations

The CD requires that the hydraulic model be used in conjunction with available flow monitoring to evaluate effectiveness of the Paragraph 8 construction projects. To accomplish this, two hydraulic model simulations were performed for a 2-year, 24-hour storm. The first simulation was performed with no Paragraph 8 projects in place (pre-construction). This first simulation yielded a total SSO volume of 2.17 million gallons. For the second simulation the model was modified to include the Paragraph 9 Projects (post-construction). The second simulation yielded a total SSO volume of only 0.56 million gallons, a 74% reduction in SSO volume discharging through the engineer SSO structures.

2.5 Conclusions

A comparison of pre- and post construction hydraulic model simulations show a 74% reduction in SSO volume discharging through the engineered SSO structures. This report concludes that the Paragraph 8 construction projects in the High Level Sewershed have been effective in providing additional hydraulic capacity and reducing overflows. The Paragraph 8 projects, however, have not been sufficient and additional construction projects will be necessary as identified and recommended in Sections 5 and 7 of this report.

3.0 FLOW MONITORING PROGRAM

3.1 Overall Description

In order to support the I/I analysis and calibration of the hydraulic model, the City of Baltimore completed a comprehensive City-wide monitoring program as part of the Baltimore City project No. 1028. This program consisted of over 350 flow monitors system-wide from May 9, 2006 to May 18, 2007. Some locations were deemed long term meters and remained after May 18, 2007, exceeding the required 18 months of continuous flow monitoring required by the Consent Decree. In addition to the flow monitors, 20 rain gauges were installed throughout the City and in the surrounding Baltimore County drainage areas.

The objective of flow monitoring programs is to quantify the flow conditions in sewers during both dry and wet weather conditions. Monitored data is used to support the model calibration as well as to assess the localized bottlenecks or hydraulic conditions.

Monitoring of flow, water level and velocity was performed in HLSS during several time periods. A major effort was part of the city-wide flow monitoring conducted by three flow metering contractors in the City of Baltimore, in which there was an extended monitoring record available to support the model calibration in HLSS and other sewersheds. In addition, short-term monitoring was conducted to support localized hydraulic analyses. These monitoring programs are discussed in detail here.

3.2 Metering Network Within the High Level Sewershed

Flow monitoring was conducted in HLSS at 42 locations including five boundary flow meters. Figure 3.2.1 depicts a schematic of the monitoring plan for the High Level Sewershed. Table 3.2.1 lists the meters within the sewershed, their purpose, and installation history. Map 3.2.1 depicts the location of the meters and rain gauges within the sewershed and identifies the operating period for each meter. These locations were determined by the City so that every flow meter basin had similar linear footage of sanitary pipes. The primary monitoring period for HLSS extended from May 2006 to May 2007, which captured 29 storm events greater than 0.5” in total rainfall volume. The locations BHL1, JFPS, JFOUT, OUT05 and OUT06 are boundary meters that provided information on total flows contributed by surrounding sewersheds into HLSS. Similarly, TSHL01, TSHL03, HL08A and HL09A are the locations used for macro model calibration by the technical team, 1015. As shown in Figure 3.2.1, there are 11 meters including three boundary meters that are continuously being operated by the City for long term flow monitoring.

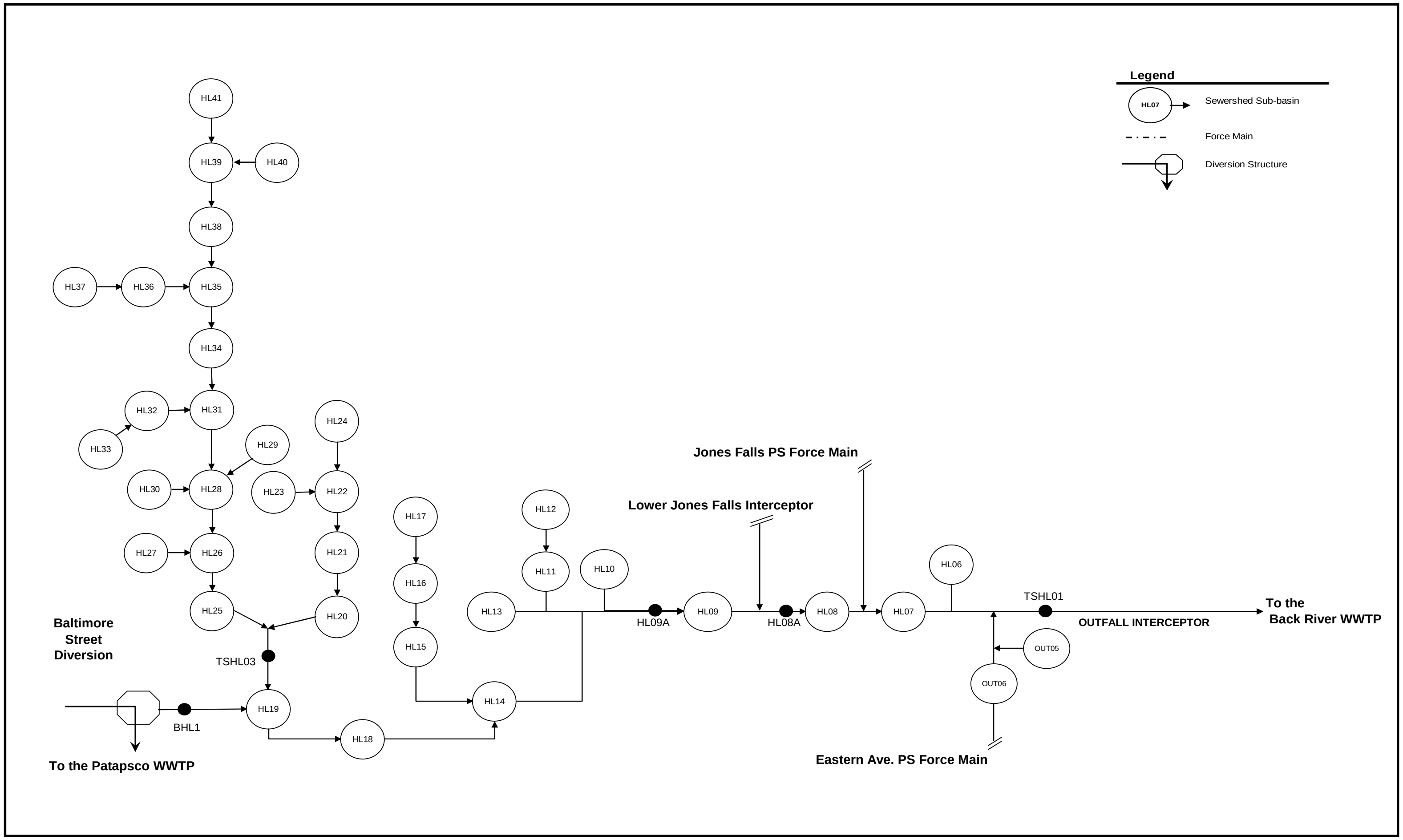


Figure 3.2.1 – High Level Flow Monitoring Schematic

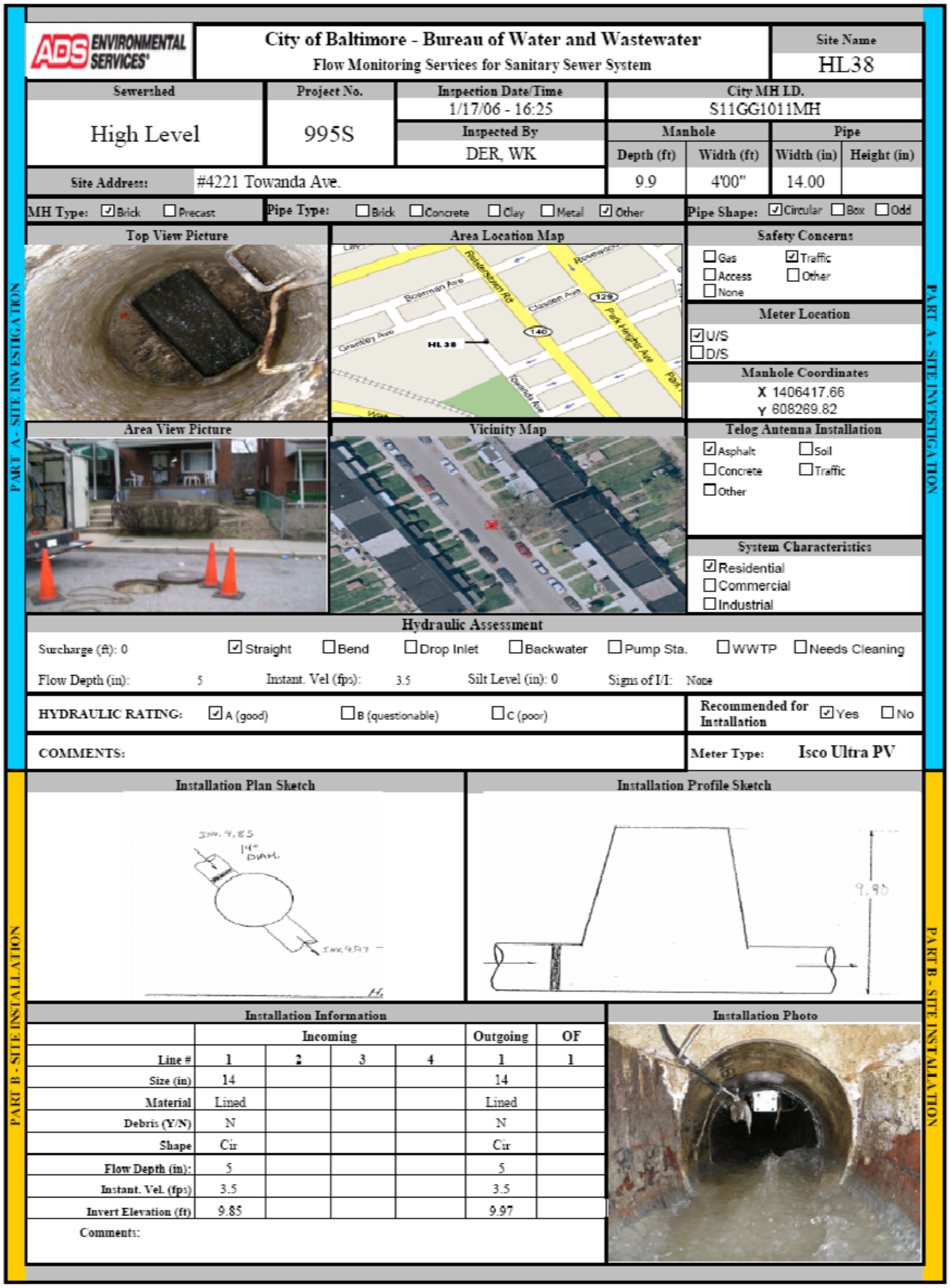
Table 3.2.1 – High Level Flow Meter Purpose and Installation History

Meter	Purpose	Installed	Removed	Meter	Purpose	Installed	Removed
BHL1	Boundary Meter	05/09/06	Long Term Meter	HL26	I/I	05/09/06	05/18/07
HL06	I/I	05/09/06	05/18/07	HL27	I/I	05/09/06	05/18/07
HL07	I/I	05/09/06	05/18/07	HL28	I/I	05/09/06	05/18/07
HL08	I/I	05/09/06	05/18/07	HL29	I/I	05/09/06	05/18/07
HL08A	Calibration Meter	05/09/06	05/18/07	HL30	I/I	05/09/06	05/18/07
HL09	I/I	05/09/06	Long Term Meter	HL31	I/I	05/09/06	Long Term Meter
HL09A	Calibration Meter	05/09/06	05/18/07	HL32	I/I	05/09/06	Long Term Meter
HL10	I/I	05/09/06	05/18/07	HL33	I/I	05/09/06	Long Term Meter
HL11	I/I	05/09/06	05/18/07	HL34	I/I	05/09/06	02/29/08
HL12	I/I	05/09/06	05/18/07	HL35	I/I	05/09/06	Long Term Meter
HL13	I/I	05/09/06	05/18/07	HL36	I/I	05/09/06	02/29/08
HL14	I/I	05/09/06	05/18/07	HL37	I/I	05/09/06	02/29/08
HL15	I/I	05/09/06	05/18/07	HL38	I/I	05/09/06	02/29/08
HL16	I/I	05/09/06	05/18/07	HL39	I/I	05/09/06	02/29/08
HL17	I/I	05/09/06	05/18/07	HL40	I/I	05/09/06	02/29/08
HL18	I/I	05/09/06	05/18/07	HL41	I/I	05/09/06	02/29/08
HL19	I/I	05/09/06	05/18/07	JFOUT	Boundary Meter	05/09/06	05/18/07
HL20	I/I	05/09/06	Long Term Meter	JFPS	Boundary Meter	05/09/06	Long Term Meter
HL21	I/I	05/09/06	05/18/07	OUT05	Boundary Meter	05/09/06	05/18/07
HL22	I/I	05/09/06	05/18/07	OUT06	Boundary Meter	05/09/06	Long Term Meter
HL23	I/I	05/09/06	05/18/07	TSHL01	Calibration Meter	05/09/06	Long Term Meter
HL24	I/I	05/09/06	05/18/07	TSHL03	Calibration Meter	05/09/06	Long Term Meter
HL25	I/I	05/09/06	05/18/07				

For each flow meter, a one-page site sheet was provided by the corresponding flow metering contractor. Figure 3.2.2 shows the site sheet for HL38 as an example. A site sheet provides information on the flow meter location, manhole/pipe structure, hydraulic data, and any miscellaneous information such as inspection date and the inspector's name. The location information includes vicinity maps, photos, manhole identification number, and the global positioning system (GPS) coordinates. Structural information includes the manhole depth, width, and material; and the pipe information includes all the incoming and outgoing pipe size, material, and invert depth. Hydraulic information provides installation photo, flow depth and velocity measured during the inspection, and silt level. These instant depth and velocity information provide useful insights when the flow monitoring data quality at a specific metering location is questionable.

The HLI exhibits complex hydraulic conditions due to interactions with the other sewersheds. In addition, the conveyance capacities of GRI have been affected due to significant variations in flows during dry/wet weather induced by significant discharge from Ashburton Water Filtration Plant (WFP). As a result, the HLI has several inflow contributions from other sewersheds, and those flows can be quite significant during dry and wet weather periods. The inflow and infiltration flows from other sewersheds, in addition to those generated within HLSS, have posed excessive surcharging and some overflows within the HLSS drainage area. As part of the City of Baltimore's comprehensive capacity assessment and rehabilitation process, several flow metering locations were established to specifically quantify the flow contributions from these sewersheds.

The location of flow meters to measure these boundary flows are shown in Figure 3.2.3, and their dry and wet weather flow rate ranges are summarized in Table 3.2.2. Each of these locations is discussed in further detail here.



ADS ENVIRONMENTAL SERVICES

City of Baltimore - Bureau of Water and Wastewater
Flow Monitoring Services for Sanitary Sewer System

Site Name	HL38

Sewershed	Project No.	Inspection Date/Time	City MH I.D.
High Level	995S	1/17/06 - 16:25	S11GG1011MH
		Inspected By: DER, WK	

Manhole Depth (ft)	Manhole Width (ft)	Pipe Width (in)	Pipe Height (in)
9.9	4'00"	14.00	

Site Address: #4221 Towanda Ave.

MH Type: ☑ Brick ☐ Precast
Pipe Type: ☐ Brick ☐ Concrete ☐ Clay ☐ Metal ☑ Other
Pipe Shape: ☑ Circular ☐ Box ☐ Odd

Top View Picture

Area Location Map

Safety Concerns: ☐ Gas ☑ Traffic ☐ Access ☐ Other ☐ None

Meter Location: ☑ U/S ☐ D/S

Manhole Coordinates: X 1406417.66 Y 608269.82

Area View Picture

Vicinity Map

Telog Antenna Installation: ☑ Asphalt ☐ Soil ☐ Concrete ☐ Traffic ☐ Other

System Characteristics: ☑ Residential ☐ Commercial ☐ Industrial

Hydraulic Assessment

Surcharge (ft): 0 ☑ Straight ☐ Bend ☐ Drop Inlet ☐ Backwater ☐ Pump Sta. ☐ WWTP ☐ Needs Cleaning

Flow Depth (in): 5 Instant. Vel (fps): 3.5 Silt Level (in): 0 Signs of I/I: None

HYDRAULIC RATING: ☑ A (good) ☐ B (questionable) ☐ C (poor)

Recommended for Installation: ☑ Yes ☐ No

COMMENTS:

Meter Type: Isco Ultra PV

Installation Plan Sketch

Installation Profile Sketch

Installation Information

	Incoming				Outgoing	OF
Line #	1	2	3	4	1	1
Size (in)	14				14	
Material	Lined				Lined	
Debris (Y/N)	N				N	
Shape	Cir				Cir	
Flow Depth (in):	5				5	
Instant. Vel. (fps)	3.5				3.5	
Invert Elevation (ft)	9.85				9.97	

Comments:

Installation Photo

PART A - SITE INVESTIGATION
PART B - SITE INSTALLATION

Figure 3.2.2 – Sample Flow Metering Site Sheet (HL38)

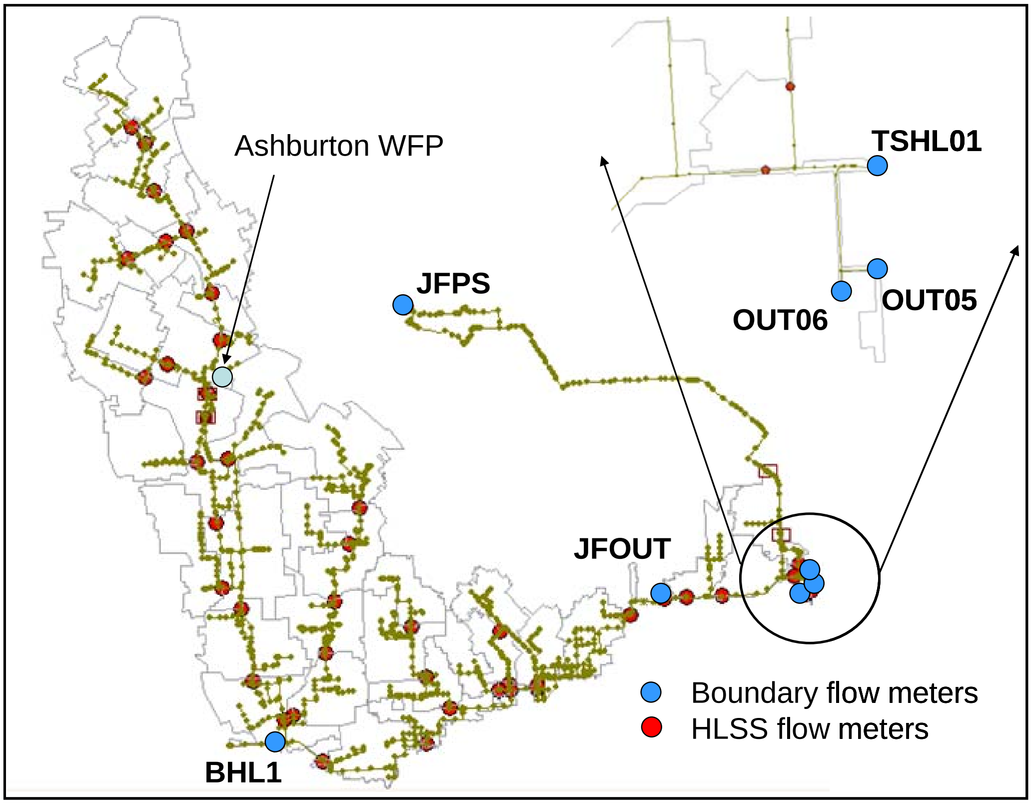


Figure 3.2.3 – Location of HLSS boundary meters

Table 3.2.2 – Dry and Wet Weather Flow Rate Range from HLSS Boundaries

Flow Sources	Flow Direction	Flow Meter	Pipe Size (in)	Dry weather flow range (MGD)	Peak wet weather flow (MGD)
Baltimore Street Diversion	Into HLI	BHL1	33"	10 - 12.5	18
Jones Falls Interceptor	Into HLI	JFOUT	78"	5 - 15	33
Jones Falls Pump Station*	Into HLI	JFPS	60"	10 - 20	66
Outfall Sewershed	Into HLI	OUT05*	15"	N/A	N/A
Eastern Avenue Pump Sation	Into HLI	OUT06	99"	10 - 40	76
HLSS and all the boundary flows	Out of HLI	TSHL01	144 (W) * 129 (H)	70 - 90	170

* Flow meter is located near pump station, upstream of Jones Falls Force Main
* OUT05 didn't work properly due to high flow fluctuation from Eastern Avenue Pump Station

A. Baltimore Street Diversion

A portion of the flow from Gwynns Falls Sewershed was diverted by the City of Baltimore to HLI at the Baltimore Street Diversion (BSD). Historically this diversion was activated when the total flows to the Patapsco WWTP were excessive. The control valve to HLI, that was used to divert excessive flows to the Back River WWTP, has been closed since November 2007. However, several short periods of flow diversion is seen in the recent data during wet weather. The City is planning to minimize this wet weather flow into HLI, since it has capacity limitations and potential SSO problems near its downstream end. The flow from BSD was measured at the flow meter BHL1 (see Figure 2-1), and the flow rate ranged from 10 to 12.5 million gallons per day (MGD) during the recent monitoring period. The BSD flow rate exceeded 15 MGD three times during the primary flow monitoring period (May 2006 to May 2007) for HLSS drainage area.

B. Jones Falls Sewershed

A portion of the flow from Jones Falls Sewershed is conveyed to the HLI through the Lower Jones Falls (LJF) Interceptor. The LJF interceptor is a 75" pipe that joins HLI at a location downstream of the inverted siphon that crosses the Jones Falls Express Way (I-83). Flow from this interceptor was measured by the flow meter JFOUT. The flow rate ranged, during dry weather periods, between 5 and 15 MGD, and increased to about 35 MGD during wet weather periods.

The 75" LJF Interceptor connects to the 66" HLI at approximately 21" below from the HLI invert level at the junction point. Also, the downstream portion of LJF interceptor has experienced frequent surcharging and overflows due to flow back-up from the HLI. Therefore, the City has built a new relief pipe, called the Greenmount Interceptor, and connected to HLI approximately 1,200 feet east of the LJF interceptor. The Greenmount Interceptor has been put in service since May 2008. Since this is new construction, it will be included in the hydraulic analyses of the baseline and future rehabilitation scenarios, and not in the model calibration process that will essentially use the May 2006 to May 2007 data.

C. Jones Falls Force Main

The Jones Falls Force Main (JFFM) carries flow from remainder of the Jones Falls sewershed sent through the Jones Falls Pump Station. This conveyance system consists of 17,000 feet long 36" pressurized sewer (force main) section and a 4,000 feet long gravity section prior to joining the HLI. The gravity section includes a 36" existing sewer and a newly constructed 42" sewer line, SC-779, which has been in service since 2004. SC-779 was construction as part of other City Paragraph 8 projects (e.g., Jones Falls Pump Station upgrade project SC-822) to eliminate SSO No.5 which is an overflow weir at Jones Falls Pump Station. The discharge from the pump station to HLI is 10 – 20 MGD for dry period, however, the discharge increases up to 70 MGD for wet period.

D. Eastern Avenue Pump Station

The Eastern Avenue force main carries flow from the Eastern Avenue Pump Station. It is the largest boundary flow contributor to the HLI and this pump station collects flow from the entire Low Level Sewershed and sends it to the downstream end of HLI. The flow rate was measured at the meter OUT06 installed at the downstream end of the gravity section of Eastern Avenue force main. This discharge ranged from 10 to 40 MGD during dry days and peaked to about 80 MGD during wet weather periods. However, this 100" pipe had about 25" depth of sediment according to the flow metering location's site sheet, and the depth of flow during dry weather was between half to ¾ of pipe diameter. This high depth flow appears to create regular flow back-up in lateral sewer in the Outfall Sewershed, OUT05, as evidenced by the difficulty in obtaining any reliable flow monitoring data from this location.

E. Outfall Sewershed

A smaller drainage area at the west end of Outfall sewershed contributes flow to the HLI through the large pipe that conveys flow from the Eastern Avenue Pump Station. The flow was measured at flow meter OUT05. As mentioned above, the gravity section of the Eastern Avenue force main creates surcharging conditions at this 15" lateral pipe on a daily basis. Therefore, the flow monitoring at this location was extremely difficult throughout the monitoring period due to high fluctuations in flows from the Eastern Avenue Pump Station

F. TSHL01

The total flow from HLI and the other contributing sewersheds was monitored at a downstream location near the end of HLI, TSHL01. As shown in Table 2-1, total flow contributions from these incoming boundary flows constitutes a large portion of TSHL01 flow. The flow rate at TSHL01 provides inflow boundary condition for the Outfall sewershed. The observed depth at TSHL01 provides hydraulic boundary conditions (specified as hydraulic gradient line, HGL) for HLSS that represents the ability of HLSS to send flows to the downstream Outfall Interceptor sewer towards the Back River WWTP.

The flow monitoring contractors performed independent depth and velocity measurements (field confirmations or calibrations) across the full range of depths during dry and wet weather conditions throughout the project duration, assessed monitor performance relative to these measurements, and made any necessary adjustments to the equipment to maximize the accuracy of the data with respect to actual conditions. A total of 571 field confirmations were scheduled and performed throughout the flow monitoring period – see Attachment 3.2.1 for details.

3.3 Rainfall Measurement

Rainfall data is critical for hydraulic model calibration and I/I quantification. For I/I evaluation, rainfall data is used to determine the amount of total rainfall volume for each storm event and each basin, and to calculate the ratio of RDII to the total rainfall volume (capture coefficient) to evaluate the severity of RDII. For hydraulic model calibration, rainfall data is used as wet weather event input to simulate the RDII responses.

In accordance with the CD requirements, the City had collected rain gauge-adjusted Doppler radar-rainfall data (termed simply as the Radar rain data) as well as rain gauge data measured at several point locations in the City. The network of rain gauge stations was set up to ensure a minimum coverage of one rain gauge station per 10 square miles. Figure 3.3.1 on the following page presents the network of rain gauges in the City and County. Both Radar and rain gauge data were provided for each subsewershed team by the City of Baltimore through 1014/1015. The general recommendation from the City was to use the radar rainfall data.

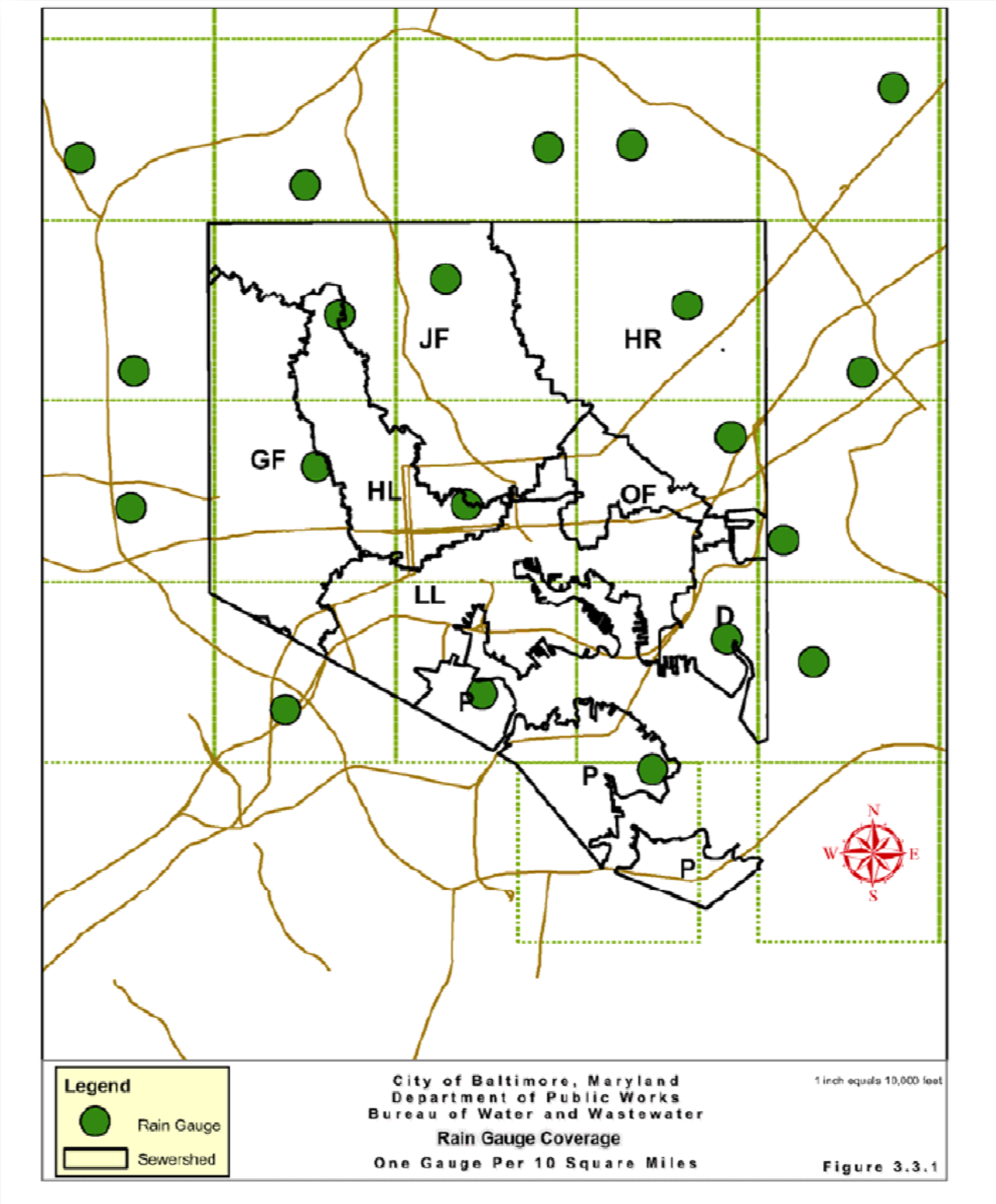


Figure 3.3.1 – Rain Gauge Network

3.4 Doppler Radar Analysis

In accordance with the CD requirements, the City performed Doppler radar rainfall analysis in conjunction with rain gauges installed at a resolution of one gauge for every 10 square miles. The contractor utilized a CALAMAR software platform to process each recorded rainfall event with an average total depth of greater than 0.5 inches of rain. This is a tool used to study the hydrologic impacts of precipitation through a combination of radar images and a network of rain gauges installed over a geographic area. CALAMAR uses three databases: a radar image database, a rain gauge database and a geographical database. After collecting the rain gauge network data and the radar images, CALAMAR produces a model that provides geographically accurate, integrated rainfall intensity data for any pre-defined area. The Baltimore City geographical area was divided into 1 square kilometer pixels, and for every significant rain event Doppler Radar rainfall images were generated for every pixel within the Back River and Patapsco WWTP service areas. There were a total of 29 storms, termed as global storms, recorded during the primary flow monitoring period. These major precipitation events, called global storms, had been pre-selected by 1014/1015 to establish consistency among individual sewersheds and also to support a regional model calibration once the individual sewershed calibrations were completed. The dates of those storm events are listed in Table 3.4.1.

Table 3.4.1 – Storm Period and Depth for Global Storms

No.	Rain Start	Rain End	Storm Period (hr)	Storm Depth (in)		
				GF07RG	GF09RG	JF12RG
1	5/11/2006 12:00	5/11/2006 22:00	36	1.7	2.1	1.46
2	5/14/2006 23:00	5/15/2006 16:00	48	1.06	0.75	0.95
3	6/2/2006 19:00	6/3/2006 6:00	24	0.65	1.58	0.55
4	6/19/2006 14:00	6/19/2006 16:00	24	0.39	0.96	0.26
5	6/24/2006 13:00	6/24/2006 22:00	18	0.92	0.53	0.87
6	6/25/2006 4:00	6/26/2006 22:00	144	6.33	6.1	5.92
7	7/5/2006 11:00	7/6/2006 6:00	96	2.47	1.44	3.21
8	7/22/2006 14:00	7/23/2006 0:00	24	0.65	1.04	0.49
9	9/1/2006 6:00	9/2/2006 17:00	60	2.21	2.19	2.37
10	9/5/2006 2:00	9/5/2006 17:00	48	1.7	1.15	2.17
11	9/14/2006 1:00	9/14/2006 21:00	72	1.35	1.22	1.15
12	9/28/2006 17:00	9/28/2006 22:00	36	0.77	0.84	0.82
13	10/5/2006 20:00	10/6/2006 16:00	120	1.81	1.53	1.7
14	10/17/2006 7:00	10/18/2006 2:00	36	1.26	1.26	1
15	10/19/2006 20:00	10/20/2006 11:00	36	0.45	0.54	0.44
16	10/27/2006 15:00	10/28/2006 8:00	60	1.96	2.01	1.89
17	11/7/2006 20:00	11/8/2006 15:00	60	1.41	1.54	1.33
18	11/16/2006 8:00	11/16/2006 17:00	120	2.31	1.74	2.3
19	11/22/2006 11:00	11/23/2006 3:00	96	0.96	0.85	0.92
20	12/22/2006 12:00	12/23/2006 3:00	60	1.35	1.34	1.16
21	12/25/2006 12:00	12/26/2006 1:00	72	0.57	0.57	0.57
22	12/31/2006 16:00	1/1/2007 14:00	72	1.04	0.96	0.92
23	1/7/2007 17:00	1/8/2007 16:00	72	0.91	0.88	0.86
24	3/1/2007 18:00	3/2/2007 9:00	96	1.15	1.09	0.88
25	3/15/2007 16:00	3/16/2007 17:00	144	2.23	2.16	2.41
26	3/23/2007 13:00	3/24/2007 10:00	72	0.43	0.56	0.36
27	4/4/2007 3:00	4/4/2007 9:00	24	0.39	0.33	0.5
28	4/11/2007 21:00	4/12/2007 6:00	48	0.9	0.93	0.94
29	4/14/2007 19:00	4/16/2007 3:00	120	2.47	2.36	2.58

3.5 Data Collection, Data Processing and QA/QC Process

Sli/icer is a data analysis and management tool useful for analyzing I/I in sanitary sewer systems using rainfall and flow monitoring data. Similar to InfoWorks for citywide hydraulic modeling, the City has chosen Sli/icer as the uniform tool to be used for data analyses. It makes the data interpretation process quicker and easier, and a major advantage is the display of rainfall and flow data in various graphical windows that enable users to interpret the sewer hydraulic conditions. With 42 flow-metering sites in place, HLSS had vast amount of data collected from May 2006 to May 2007 that were analyzed using Sli/icer. In addition to the flow/water level/velocity analyses, it has other useful elements for model development including spatial interpolation of point gage data using quadrant method, radar rainfall grid and associated data, and the analysis of design storms for comparison with historical storms.

The HLSS Sli/icer database includes information from all flow meters within HLSS as well as the boundary meters (e.g., Lower Jones Falls Interceptor), and rain data for each flow basin. Both raingage and radar data were available in Sli/icer, and we could select either of the datasets to support the DWF and RDII analysis. Rainfall and flow data, depicted in Figure 3.5.1, could be exported for a specific duration (event or continuous periods) for further analysis and model input preparation. Sli/icer also has in-built functions to analyze the DWF and RDII. The users can process flow data to obtain both DWF and RDII parameters.

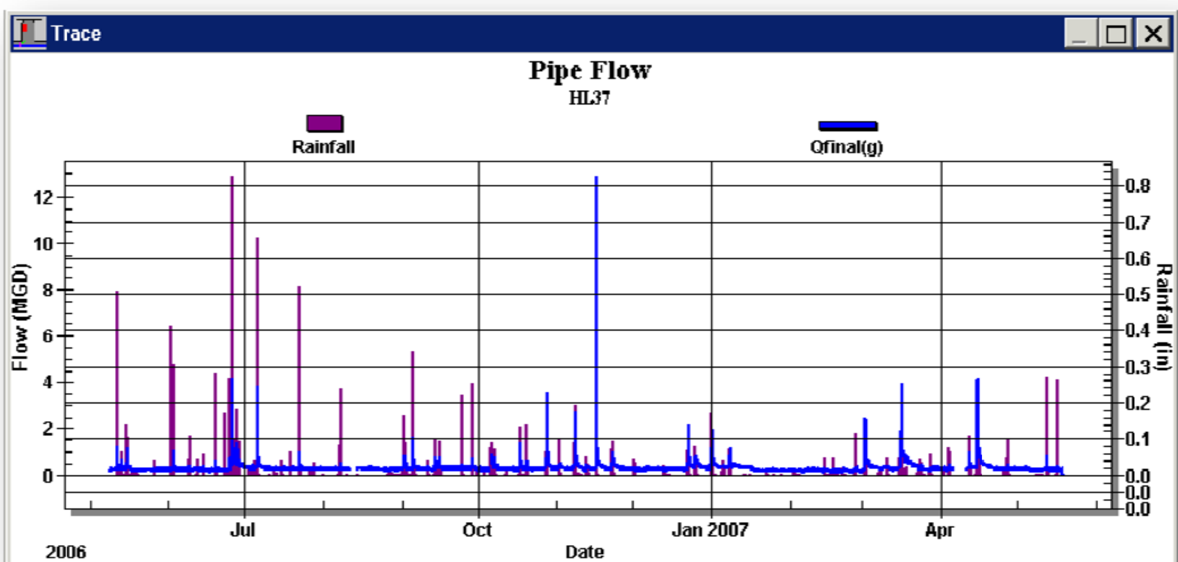


Figure 3.5.1 – Flow Data from May 2006 to May 2007

3.6 Dry Weather Analysis

Following the criteria established in the BaSES manual, the dry days were defined in accordance with Table 3.6.1.

Table 3.6.1 – Dry Day Criteria

Number of Prior Days	Cumulative Antecedent Rain (Inches)
1	0.1
3	0.4
5	1.0

In addition, the dry days with total flows that are 15 percent higher or lower than the average volume of all dry days were excluded from the analysis. Subsequently the dry day traces for each meter were edited to remove any outliers that might have passed through the filtering requirements. Finally, the Sli/icer was used to calculate the Average Dry Day Flow (ADDF) from all the traces.

3.6.1 Base Infiltration Rates and Severity

The wastewater production (WWP) was calculated by subtracting the base infiltration (BI) from ADF. As required, the Stevens-Schutzbach Method was used to determine the base infiltration (BI). The Stevens-Schutzbach Method is as follows:

$$BaseInfiltration = \frac{0.4 \times MDF}{\left(1 - \left(0.6 \times \left(MDF \big/ ADF\right)^{\left(MDF\right)^{0.7}}\right)\right)}$$

where ADF is the Average Daily Flow rate and MDF is the Minimum Daily Flow rate.

Table 3.6.2 shows the results of the dry–weather flow analysis. There were several issues summarized in this table that are primarily attributable to flow imbalances. The cells and corresponding basin names are highlighted in gray if the:

1. Calculated WWP or BI values were negative;
2. Calculated WWP rate exceeded 35 (gallons per linear foot - gal/LF), whereas the reasonable value for WWP rate is 5 – 20 (gal/LF.); or
3. Calculated WWP was less than 50 % of winter 2007 water consumption.

Normalizing BI is important for comparing different flow basins with severe infiltration problems. A simple interpretation of infiltration rates does not always lead to right conclusions about the locations of worst problems in a collection system. For this project, the BI was normalized based on inch-diameter-miles (IDM). The IDM normalization was selected for BI because it took into account not only the length, but also the diameter of pipes in the basin. Regardless of the length, the larger the pipe diameter the more pipe surface would be exposed to leakage from groundwater. The Sli/icer provides this type of BI normalization for each basin.

The calculated BI severity from the summer 2006 HL25-TSHL03 aggregation, 2,329 (gpd/idm), was considered as average BI severity for the lower GRI (i.e., HL25, 26, 28, 31, and TSHL03). Table 3.6.3 shows the modified results of the dry weather flow analysis. Figure 3.6.1 shows the winter BI normalized by inch-diameter of pipes for each flow basin.

Acronyms found in Table 3.6.2 are defined as follows

- Agross – Entire drainage area contributing to the meter, including upstream meter basins.
- Anet – Net area draining to the meter, excluding any upstream meter basins.
- IDM – Inch-Diameter-Mile. A parameter used to evaluate infiltration severity. It is calculated by summing the product of pipe length (in miles) times pipe diameter (inches) for all sewer pipes in the meter basin.
- ADF – Average Dry-weather Flow represents the average flow measured during dry-weather conditions in millions of gallons per day, and includes groundwater infiltration. The “gross” includes entire drainage area, while “net” excludes flow measured at upstream basins.
- Qnet/Qgross – This is the ratio of the net average dry weather flow to gross average dry weather flow.
- WWP – Wastewater Production represents the estimated sanitary flow generated strictly from human activities during dry-weather conditions in millions of gallons per day, and excludes groundwater infiltration. Net flow excludes that from upstream meter basins.
- BInet – Base Infiltration (net) represents the average groundwater leaking into the sanitary sewer pipes during dry-weather conditions in millions of gallons per day, excluding base infiltration from upstream meter basins.
- BI Severity – This is the net base infiltration in gallons per day divided by the inch-diameter-miles of pipe within the meter basin.
- BI Rate – This is the ratio of net base infiltration to net average daily flow expressed as percent.
- WWP Rate – This is the ratio of the net wastewater production in gallons divided by the linear footage of pipes within the meter basin

Table 3.6.2 – Dry Weather Analysis (Winter 2007 - Weekdays Only)

Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} (MGD)	ADF_{net} (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption (MGD)	WWP (MGD)	BI_{net} (MGD)	BI Severity (gpd/idm)	BI Rate (%)	WWP Rate (gal/l.f.)
HL06	94	94	100.0	46.0	0.43	0.43	100.0	0.15	0.13	0.30	6564	70.2	4.7
HL07	4518	81	1.8	82.1	46.88	8.73	18.6	0.12	8.05	0.68	8328	7.8	388.9
HL08	4308	87	2.0	65.6	38.15	1.95	5.1	0.16	0.96	0.99	15061	50.8	35.3
HL09	4096	120	2.9	126.8	34.18	8.33	24.4	0.44	4.38	3.95	31178	47.4	138.3
HL10	85	85	100.0	32.5	0.33	0.33	100.0	0.17	0.13	0.21	6365	62.2	6.5
HL11	141	64	45.0	27.9	0.45	0.19	41.1	0.05	0.09	0.10	3555	53.2	5.6
HL12	78	78	100.0	34.0	0.27	0.27	100.0	0.11	0.12	0.15	4295	54.7	5.8
HL13	68	68	100.0	30.6	0.34	0.34	100.0	0.18	0.10	0.25	8020	72.1	5.0
HL14	3915	84	2.1	82.0	20.02	0.00	0.0	0.14	-1.03	-0.77	-9350	42.7	-42.1
HL15	310	88	28.3	44.3	0.93	0.19	20.6	0.12	0.07	0.13	2822	65.4	2.6
HL16	222	132	59.5	60.2	0.74	0.15	20.3	0.19	0.01	0.14	2278	91.9	0.3
HL17	90	90	100.0	39.5	0.59	0.59	100.0	0.16	0.23	0.36	8992	60.5	9.4
HL18	3540	125	3.5	98.7	20.89	0.58	2.8	0.23	1.10	-0.58	-5826	-	28.0
HL19	3416	54	1.6	38.0	20.37	1.22	6.0	0.12	3.08	-1.87	-49132	-	229.8
HL20	704	119	16.8	52.4	2.44	0.88	35.9	0.23	0.54	0.34	6392	38.2	20.3
HL21	585	132	22.6	47.9	1.57	0.42	26.7	0.24	0.18	0.24	4995	57.0	6.5
HL22	453	140	30.8	63.3	1.15	0.39	33.9	0.28	0.19	0.20	3221	52.3	5.7
HL23	92	92	100.0	37.0	0.26	0.26	100.0	0.19	0.13	0.13	3514	50.2	5.6
HL24	222	222	100.0	63.1	0.50	0.50	100.0	0.31	0.18	0.32	5006	63.2	4.9
HL25	2545	172	6.8	72.8	4.94	0.44	9.0	0.30	0.82	-0.46	-6308	-	22.0
HL26	2372	221	9.3	71.3	4.58	0.00	0.0	0.30	-0.60	-1.91	-26782	76.2	-16.1
HL27	147	147	100.0	59.0	0.51	0.51	100.0	0.26	0.21	0.29	4949	57.8	5.9
HL28	2004	235	11.7	57.1	6.58	6.02	91.5	0.15	2.81	3.21	56235	53.3	101.9
HL29	200	200	100.0	41.4	0.15	0.15	100.0	0.10	0.07	0.08	1885	52.3	3.1
HL30	139	139	100.0	51.1	0.41	0.41	100.0	0.19	0.07	0.34	6579	82.4	2.2
HL31	1430	176	12.3	53.6	0.00	0.00	0.0	0.14	0.00	0.00	0	0.0	0.0
HL32	249	116	46.7	32.4	0.31	0.05	14.7	0.09	0.03	0.01	432	29.8	1.6
HL33	132	132	100.0	32.1	0.27	0.27	100.0	0.10	0.06	0.21	6476	78.2	2.8
HL34	1006	76	7.5	27.1	2.39	0.00	0.0	0.11	0.42	-0.78	-28714	214.6	26.8

Table 3.6.2 – Dry Weather Analysis (Winter 2007 - Weekdays Only) (Cont.)

Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} (MGD)	ADF_{net} (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption (MGD)	WWP (MGD)	BI_{net} (MGD)	BI Severity (gpd/idm)	BI Rate (%)	WWP Rate (gal/l.f.)
HL35	930	161	17.4	61.0	2.75	0.39	14.1	0.20	0.05	0.34	5594	88.3	1.3
HL36	244	65	26.5	19.9	0.70	0.43	61.8	0.07	0.18	0.26	12915	59.5	14.7
HL37	179	179	100.0	44.3	0.27	0.27	100.0	0.18	0.09	0.18	3951	65.5	3.2
HL38	525	133	25.2	36.2	1.67	0.93	55.9	0.16	0.20	0.73	20133	78.1	9.4
HL39	392	123	31.4	48.5	0.74	0.06	8.6	0.16	0.04	0.03	578	43.8	1.3
HL40	160	160	100.0	33.7	0.33	0.33	100.0	0.17	0.11	0.23	6712	68.1	4.9
HL41	109	109	100.0	35.4	0.34	0.34	100.0	0.11	0.13	0.21	5989	62.2	6.2
TSHL03	3249	113	3.5	40.0	7.60	0.00	0.0	0.08	-13.41	-1.29	-32284	8.8	-744.5

* Cells were grayed out when WWP or BI is negative; WWP Rate exceeds 35 (gal/l.f.); WWP is less than 50% of water consumption; or Anet/Agross is less than 20%

A_{gross} (acres) = Total area of the upstream tributary area at this meter location

A_{net} (acres) = Individual net tributary basin area calculated by subtracting the gross area of the upstream meters from the gross area of the specified meter

A_{gross}/A_{net} (%) = Percentage of the net tributary basin relative to the total upstream tributary area

IDM (In-dia-mile) = Used to represent the surface area of the pipe within the basin over which infiltration can enter the system and is calculated as the diameter of the pipe (in inches) multiplied by the miles of pipe length; it is used to normalize the infiltration between basins of differing size by the pipe diameter and length

ADF_{gross} (MGD) = Total average daily flow for the total upstream tributary area as collected at this meter location

ADF_{net} (MGD) = Individual net average daily flow for the basin area calculated by subtracting the gross average daily flows of the upstream meters from the total gross average daily flow of the specified meter

Q_{net}/Q_{gross} (%) = Percentage of the net basin average daily flow relative to the total upstream average daily flow

Water Consumption (MGD) = Water usage volume per day within the metered basin area obtained from City of Baltimore records

WWP (MGD) = Wastewater Production calculated by subtracting the base infiltration (BI) from average daily flow (ADF)

BI_{net} = Base Infiltration calculated according to the Stevens-Schutzbach Method representing the amount of infiltration entering the system during dry weather conditions

BI Severity (gpd/idm) = A normalized measure of the severity of the base infiltration within a basin calculated by dividing the net base infiltration by the inch-diameter-mile of pipe within the upstream area

BI Rate (%) = Percentage of the average daily flow attributed to base infiltration calculated by dividing the net base infiltration by the net average daily flow

WWP Rate (gal/l.f.) = Wastewater production rate calculated as the volume of wastewater (obtained by subtracting base infiltration from the average daily flow) normalized by the pipe length within the basin

Table 3.6.3 – Modified Dry Weather Analysis (Winter 2007 - Weekdays Only)

Basin	A_{gross} (acres)	A_{net} (acres)	A_{net}/A_{gross} (%)	IDM (in-dia-mile)	ADF_{gross} (MGD)	ADF_{net} (MGD)	Q_{net}/Q_{gross} (%)	Water Consumption(MGD)	WWP (MGD)	BI_{net} (MGD)	BI Severity**** (gpd/idm)	BI Rate (%)	WWP Rate (gal/l.f.)
HL06	94	94	100.0	46.0	0.43	0.43	100	0.15	0.13	0.30	6,564	70.2	4.7
HL10	85	85	100.0	32.5	0.33	0.33	100	0.17	0.13	0.21	6,365	62.2	6.5
HL11	141	64	45.0	27.9	0.45	0.19	41	0.05	0.09	0.10	3,555	53.2	5.6
HL12	78	78	100.0	34.0	0.27	0.27	100	0.11	0.12	0.15	4,295	54.7	5.8
HL13	68	68	100.0	30.6	0.34	0.34	100	0.18	0.10	0.25	8,020	72.1	5.0
HL15-16	532	220	87.8	104.5	0.93	0.34	37	0.32	***0.27***	***0.07***	***623***	***19.1***	***4.5***
HL17	90	90	100.0	39.5	0.59	0.59	100	0.16	0.23	0.36	8,992	60.5	9.4
HL20	704	119	16.8	52.4	2.44	0.88	36	0.23	0.54	0.34	6,392	38.2	20.3
HL21	585	132	22.6	47.9	1.57	0.42	27	0.24	0.18	0.24	4,995	57.0	6.5
HL22	453	140	30.8	63.3	1.15	0.39	34	0.28	0.19	0.20	3,221	52.3	5.7
HL23	92	92	100.0	37.0	0.26	0.26	100	0.19	0.13	0.13	3,514	50.2	5.6
HL24	222	222	100.0	63.1	0.50	0.50	100	0.31	0.18	0.32	5,006	63.2	4.9
HL27	147	147	100.0	59.0	0.51	0.51	100	0.26	0.21	0.29	4,949	57.8	5.9
HL29	200	200	100.0	41.4	0.15	0.15	100	0.10	0.07	0.08	1,885	52.3	3.1
HL30	139	139	100.0	51.1	0.41	0.41	100	0.19	0.16	0.25	4,817	60.3	4.9
HL32-33	381	249	146.7	64.6	0.31	0.31	100	0.20	***0.17***	***0.14***	***2,196***	***45.4***	***4.1***
HL34-35	1935	237	24.9	88.1	2.39	0.39	16	0.31	***0.27***	***0.12***	***1,318***	***29.9***	***5.4***
HL36	244	65	26.5	19.9	0.70	0.43	62	0.07	0.18	0.26	12,915	59.5	14.7
HL37	179	179	100.0	44.3	0.27	0.27	100	0.18	0.09	0.18	3,951	65.5	3.2
HL38-39	917	255	56.6	84.6	1.67	1.00	60	0.32	0.24	0.76	8,920	75.9	4.8
HL40	160	160	100.0	33.7	0.33	0.33	100	0.17	0.11	0.23	6,712	68.1	4.9
HL41	109	109	100.0	35.4	0.34	0.34	100	0.11	0.13	0.21	5,989	62.2	6.2
Lower GRI**	3249	917	28.2	295	8.70	1.65	19	0.97	***0.84***	***0.69***	***2,329***	***44.9***	***5.7***
HLI***	4518	551	12.2	493	46.77	2.82	6	1.21	***1.05***	***1.61***	***3,273***	***60.6***	***6.7***

* Sites that were combined and represented as one basin due to flow imbalance issue in the upstream basin are represented in red and italic font.

** Water consumption rate was used for WWP when WWP from Sli/icer is less than 50% of the water consumption

*** Lower GRI basins consist of HL25, 26, 28, 31, and TSHL03

**** HLI basins consist of HL07, 08, 09, 14, 18 and 19

***** BI Severity for Lower GRI basins was calculated based on Summer 2006 results

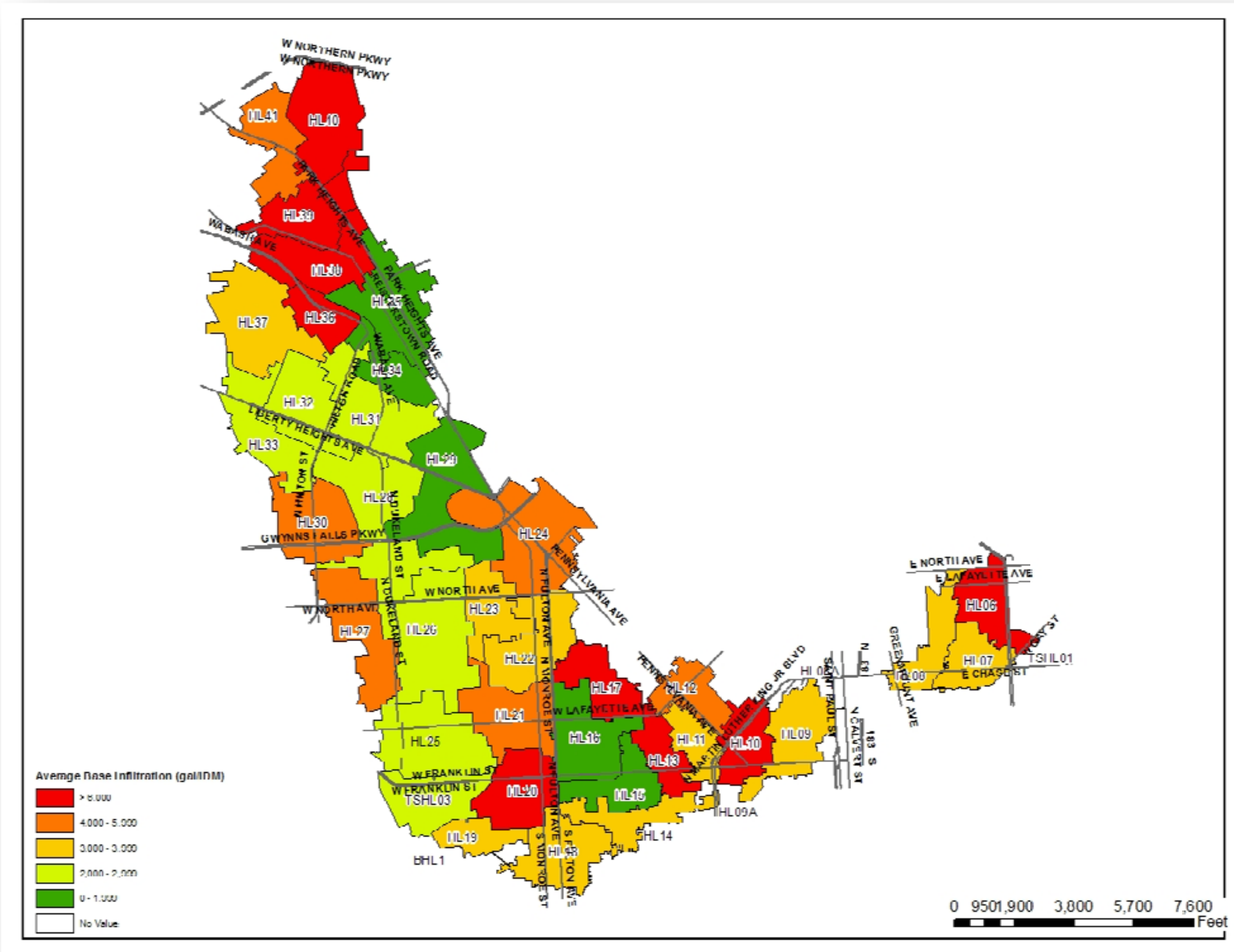


Figure 3.6.1 – Normalized Winter Base Infiltration

3.6.2 Correlation with Completed CCTV and Manhole Inspections

As a part of dry weather flow analysis, the HLSS team utilized CCTV databases to count the infiltration defects and summarize them for each flow basin. Table 3.6.5 lists the ranking for each of the basins with the highest quantity of Base Infiltration against the ranking for the number of infiltration defects found during the CCTV inspection.

Table 3.6.5 – Base Infiltration and Infiltration Defect Rank Comparison

Basin	Average Base Infiltration Rank	Infiltration Defect Rank
HL36	1	31
HL17	2	1
HL38	3*	25
HL39	3*	3
HL13	5	14
HL40	6	11
HL06	7	8
HL20	8	2
HL10	9	33

* HL38 and HL39 were combined for the BI evaluation

As seen from Table 3.6.5, there is little correlation found between the average BI and the infiltration defects found during CCTV.

3.6.3 Influence of Groundwater Table on Infiltration Rates

Because of fluctuating groundwater table conditions, the Base Infiltration rates were separated and processed for three seasons: Summer 2006, Winter 2007 and Summer 2007. The ground water table was typically higher in the winter months as surrounding vegetation required less groundwater for plant growth. Conversely, the ground water table was much lower in the summer from a combination of drier soils due to evapotranspiration and vegetation growth. Consequently, as the groundwater table rises, the infiltration rates within the adjacent sewers increase as well. Therefore, to properly account for these seasonal differences, the HLSS team utilized separate BI rates and these values were entered as trade flow in InfoWorks for the three seasons, and distributed between each subcatchment within the flow basin based on their area proportions. For several sites that had inaccurate data, necessary assumptions were made to estimate the BI values.

3.7 Wet Weather Analysis

A total of 29 storms during the metering period met the criteria for a storm event as defined by the global settings (see Table 3.4.1). Each storm was analyzed for each flow meter using the Sliicer.com software.

For each storm, a pre-composition period (typically 24 hours prior to the storm event) was established to adjust the dry day hydrograph to match the actual hydrograph immediately prior to the start of a storm event. This either raises or lowers the dry day hydrograph so that the calculated rainfall-dependent infiltration and inflow (RDII) is a result of only this storm event.

Sliicer.com calculates I&I components for three periods following the start of a storm event. These are called Storm, Recovery 1 and Recovery 2. Each period, by default, was 24 hours long based on the global settings. For this project, however, the storm periods were set by the City, are specific for each storm, and are long enough to capture all the RDII behavior. The recovery periods 1 and 2 were set to 60 minutes, but were not used in any calculations.

In order to estimate the RDII, Sli/icer superimposes the typical dry-day hydrograph on a storm hydrograph. The difference between two hydrographs represents the RDII pattern.

3.7.1 Observed Peak Flows

Peak flow data collected during the flow monitoring period at each meter site for the 24 selected storm calibrations is shown in Appendix 2 of the revised Hydraulic Model Development and Calibration Report (Attachment 5.2.1).

3.7.2 Rain Dependent I/I (RDII) Rates and Severity

In order to estimate the RDII, Sli/icer superimposes the typical dry-day hydrograph on a storm hydrograph. The difference between two hydrographs represents the RDII pattern.

Normalizing the RDII is important when comparing results to determine the worst basins for immediate I&I control. A simple interpretation of most raw wet weather flow does not always lead to right conclusions about the locations of worst I&I problems in a collection system. Although the raw I&I information is part of the picture, it needs to be correlated with basin size and rainfall information before it can be used. For this project, the RDII was normalized based on linear footage (gal/l.f./in-of-rain). Sli/icer provides this type of normalization for each meter for each storm.

A graphical technique for evaluating and comparing the performance of sewershed basins under widely varying rain events is the Q versus I diagram. "Q" is the calculated I&I flow rate for a storm and "I" is the corresponding rainfall. The slope (S) of regression line on the Q vs. I plot was used in the following equation to obtain the capture coefficient (R). A capture coefficient represents the percentage of the volume of rain water that falls on a basin and finds its way into the collection system.

$$R = (36.83 \text{ (acres-in/mg)} * S \text{ (mg/in)}) / \text{Area (acres)}$$

There were difficulties in determining the RDII rates for some flow basins in HLSS including the interceptor basins where the net basin area was less than 20% of the gross area. A basin aggregation process was not successful for the interceptor basins due to highly varying boundary flows from the Ashburton WFP and the significant amount of wet weather flows from other sewersheds. HL31 and its downstream basins along GRI and HLI had to be excluded from the RDII evaluation. Flow imbalance issues existed even after the interceptor flows were excluded; therefore, the HLSS team resolved the RDII flow imbalance issues primarily using the Sli/icer-calculated gross RDII values instead of the net values. The RDII imbalance resolution process is described in Section 4.4.2 of the HLSS Model Development and Calibration Report. Table 3.7.2 shows the results of the wet weather analysis and Figure 3.7.1 shows the year-round RDII severity in the HLSS.

Table 3.7.1 – Wet Weather Table

Meter	RDII Severity (gal/l.f.-in)	Capture Coefficient R (%)	RDII Severity (Rank)	Capture Coefficient R (Rank)
HL36	28.1	11.9	1	1
HL37	26.5	11.1	2	3
HL32	24.9	12.3	3	2
HL33	23.8	10.7	4	6
HL39	17.6	10.3	5	4
HL40	16.6	8.5	6	9
HL38	16.3	9.3	7	10
HL23	15.5	11.3	8	5
HL27	13.9	8.7	9	7
HL41	12.9	6.6	10	12
HL06	11.7	7.2	11	8
HL11	10.3	8.4	12	11
HL22	9.8	5.5	13	14
HL21	9.3	5.7	14	16
HL20	8.7	5.3	15	15
HL17	8.5	6.1	16	13
HL24	8.3	4.2	17	22
HL29	7.8	2.4	18	25
HL34	7.5	5.3	19	18
HL35	7.2	5.2	20	19
HL10	6.7	3.9	21	20
HL15	5.4	5.2	22	17
HL13	5.2	5.4	23	21
HL16	4.7	3	24	23
HL12	3.3	2.1	25	24
HL30	1.5	0.9	26	26
HL07	N/A	N/A	N/A	N/A
HL08	N/A	N/A	N/A	N/A
HL09	N/A	N/A	N/A	N/A
HL14	N/A	N/A	N/A	N/A
HL18	N/A	N/A	N/A	N/A
HL19	N/A	N/A	N/A	N/A
HL25	N/A	N/A	N/A	N/A
HL26	N/A	N/A	N/A	N/A
HL28	N/A	N/A	N/A	N/A
HL31	N/A	N/A	N/A	N/A
TSHL03	N/A	N/A	N/A	N/A

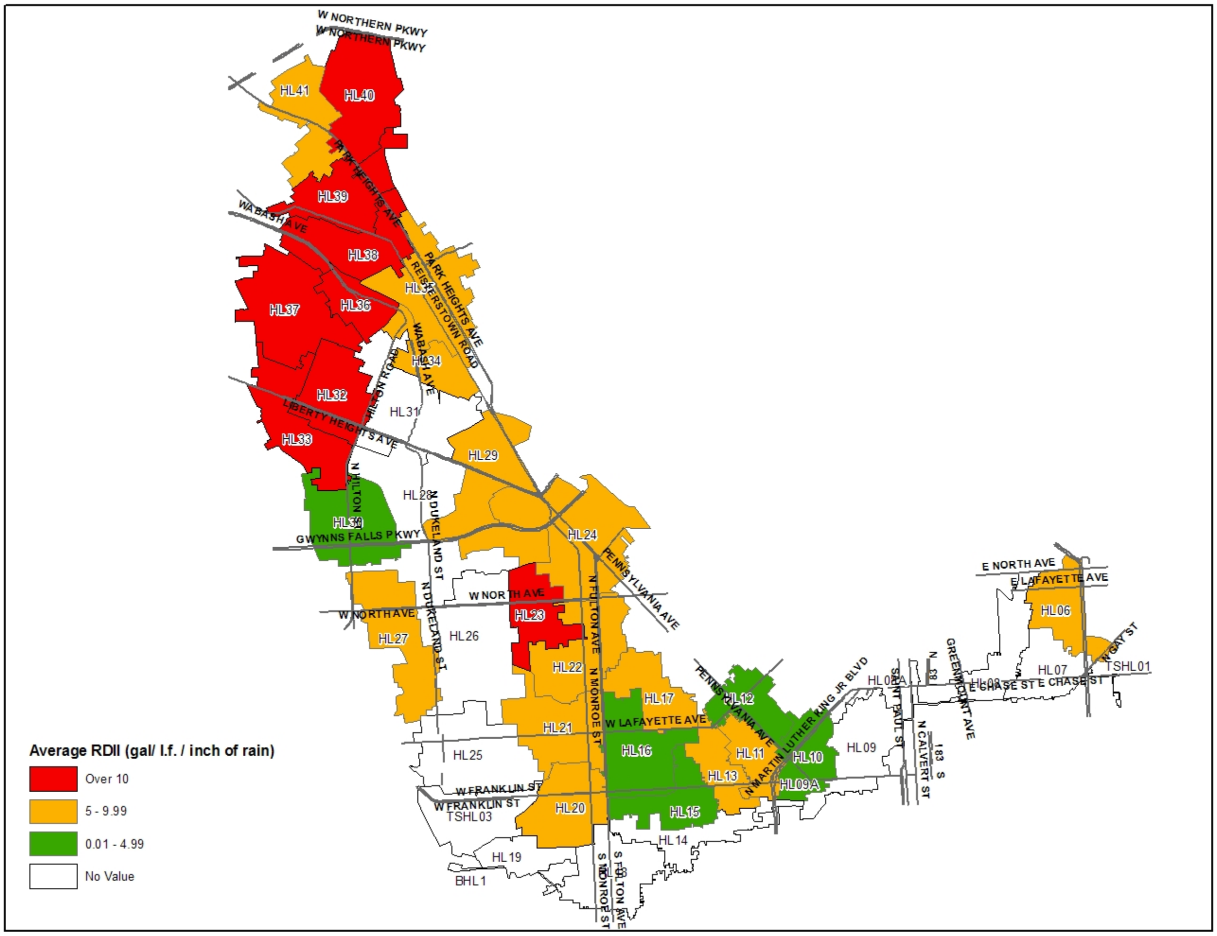


Figure 3.7.1 –RDII Severity in HLSS

The RDII severity in the HLSS, normalized by pipe length and rainfall (Figure 3.7.1), exhibited several regional patterns. The average RDII exceeded 10 (gal/l.f./inch of rain) for most basins contributing to the upper GRI, north of Ashburton WFP (HL31-41). The remaining basins (except HL 30 and some minor flow basins contributing to the HLI including: HL10, 12, 15, and 16) the average RDII was between 5 and 10 gal/l.f./inch of rain.

The scattergraph plots included in the attached CD showed the evidence of possible sanitary sewer overflows (SSOs) at some locations along the GRI and HLI. Table 3.7.3 summarizes the maximum surcharge depths and potential SSO occurrences around each flow meter.

Table 3.7.2 – Scattergraph Review Summary

Meter	Manhole Depth (in)	Pipe Height (in)	Max. Surcharge Depth (in)	Surcharge During Monitoring Period?	Maximum Surcharge Depth Greater than MH Depth?	SSO Evidence from Scattergraph ?	Notes
HL06	128.9	20	100	Yes			
HL07	135.6	100	160	Yes	Yes	Yes	SSO might have occurred at this manhole
HL08	484.8	95	165	Yes			
HL08A	270	95	170	Yes		Not clear	SSOs have repeatedly occurred at the downstream end of the HLI siphon approximately 1,000 ft upstream of HL08A with severe storms
HL09	126	82.5	130	Yes	Yes	Not clear	SSO might have occurred at this manhole
HL09A	203.8	69	115	Yes			
HL10	162.6	18	21	Yes			
HL11	196.1	18	114	Yes			
HL12	158.9	18	7				
HL13	125.5	15	56	Yes			
HL14	183.7	57	170	Yes			
HL15	159.4	24	55	Yes			
HL16	218	20	76	Yes			
HL17	183.5	15	6				
HL18	158.5	53	157	Yes		Not Clear	Maximum surcharge depth is very close to the manhole depth
HL19	659.9	52	112	Yes			
HL20	142.8	27	57	Yes			
HL21	135.7	27	25				
HL22	165	33	25				
HL23	120.6	15	15.5	Yes			
HL24	217.3	18	14.5				
HL25	228.4	33	75	Yes			
HL26	409.2	39	100	Yes			
HL27	133.3	15	62	Yes			
HL28	204.4	22	84	Yes			
HL29	306.5	18	7				
HL30	85.6	10	16.5	Yes			
HL31	147.4	24	140	Yes		Yes	SSO occurred at 2800 Dukeland St. before SC812 was installed

Table 3.7.2 – Scattergraph Review Summary (Cont.)

Meter	Manhole Depth (in)	Pipe Height (in)	Max. Surcharge Depth (in)	Surcharge During Monitoring Period?	Maximum Surcharge Depth Greater than MH Depth?	SSO Evidence from Scattergraph ?	Notes
HL32	116.4	12	27	Yes		Not clear	SSO through the remaining engineered overflow 134
HL33	165.7	12	125	Yes		Yes	SSO through the remaining engineered overflow 132
HL34	277.2	21	130	Yes			
HL35	309.6	21.25	140	Yes			
HL36	161.6	14	35	Yes			
HL37	168.4	14	55	Yes			
HL38	118.8	14	150	Yes	Yes	Yes	SSO might have occurred at this manhole
HL39	177.4	18	94	Yes			
HL40	153.6	12	92	Yes		Yes	SSO through the remaining engineered overflow 55.
HL41	137.3	14	72	Yes			
TSHL01	218.4	129	175	Yes			
TSHL03	165.6	37	70	Yes			

The flow meter manholes at HLI, HL07, HL09, and, to a lesser extent, HL18 were among the locations where the maximum surcharge was at or above the manhole rim elevation. This indicated that there had been at least one SSO event at these flow meter manholes. A known HLI manhole periodically overflows in front of the Baltimore City Detention Center (BCDC). It is not very clear in the HL08A scattergraph that a SSO ever occurred at the BCDC, which is located approximately 1,000 feet upstream of the HL08A flow meter. However, visual observations and resident complaints confirmed the occurrence of overflows. Refer to the Alternatives Analysis and Recommendations Report (Attachment 5.4.1), recently prepared by the HLSS team, for a discussion on the SSO occurrence near BCDC and recommendations to prevent further overflows around this location.

Along GRI, the maximum surcharge depth exceeded the manhole depth at HL38. The scattergraph for HL31 exhibited an evidence of recurring SSOs at or near 2800 Dukeland Street. The scattergraph of extended flow monitoring data available at HL31 suggested that the 2800 Dukeland Street SSO no longer existed. The new relief sewer constructed as part of SC 812 eliminated the potential for high surcharging or overflow at this location.

Several engineered overflows were recently abandoned and permanently plugged along the GRI. These included five engineered overflows (55, 56, 57, 130, and 131) along GRI in the vicinity of the upstream end of SC 812, and two engineered overflows (106 and 107) near the downstream end of GRI. Additional overflows could occur along GRI since these engineered overflows, which relieved flows from sanitary to storm sewers, no longer exist.

The scattergraphs at HL32 and 33 exhibited an evidence of overflow through the remaining, active engineered overflows 132, 134, and 135. Recommendations intended to eliminate these overflows are further developed in the HLSS Alternative Analysis and Recommendations Report (Attachment 5.4.1).

3.7.3 Correlation with Completed CCTV and Manhole Inspections

There are certain types of PACP defects which could be considered to result in significant amount of I&I during wet weather. However, similar to the relationship between Base Infiltration and Infiltration Defect Ratings, analysis of the relationship between the number of defects contributing to infiltration counted during the CCTV inspection and the amount of RDII within the subbasin revealed that there was no correlation between the two.

This rank analysis suggests the following:

- There may be some other PACP defects which would result in more significant RDII,
- If the RDII-related defects selected by the HLSS team were appropriate, pipe line defects were not a major source of RDII in the HLSS, and
- If the pipeline defects were not the major source of RDII in the HLSS, cross connections between storm and sanitary sewers and/or potential defects in service lines between each house and sanitary would be the major sources of RDII in the HLSS.

3.7.4 Smoke Testing Recommendations

The HLSS Team performed smoke testing comprehensively in the following 12 basins: HL 24, 25, 27, 30, 31, 32, 33, 34, 35, 36, 39, and 40. These basins were recommended for smoke testing based on the wet weather analysis and evaluation of a few additional data sources; such as GIS or as-built drawings. The results of the dry weather analysis were not considered.

Smoke testing was focused primarily on basins with high RDII severity, defined as basins with year-round capture coefficients above 5%. In particular, basins with intense peak RDII were considered good candidates for smoke testing based on the increased potential for identifying sources of inflow. The occurrence of overflows in each basin was also considered in the basin selection through review of records on reported SSOs (2003-2006) and overflow complaints (2004-2008). In addition, information on probable cross-connections between storm drains and sanitary sewers was relied on for basin selection. This information was obtained through the combined review of as-built drawings, CCTV inspection data, and manhole inspection data.

3.8 HL Sewershed Infiltration and Inflow Evaluation Report

A copy of the HL Sewershed Infiltration and Inflow Evaluation Report is found in Attachment 3.8.1.

4.0 SEWER SYSTEM EVALUATION STUDY

4.1 Overview

The High Level Collection System Evaluation and Sewershed Plan, City of Baltimore Project No. 1028 consists of a wide range of activities as defined by the Consent Decree (CD). The primary assessment conducted for each of the City of Baltimore's sewersheds is important for characterizing the condition of the system as it provides important insight into the historical nature of the collection system. The testing and inspection of the wastewater collection system in what is termed sewer system evaluation survey (SSES) is a significant part of the overall evaluation of the sewershed. These SSES activities include conducting flow monitoring and rainfall data collection programs, completing the inspection of manholes and other sewer structures located within the collection system, completing CCTV and sonar inspections of sewers 8-inches in diameter and larger, conducting smoke and dyed-water testing, the preparation, calibration and validation of a hydraulic model, and the identification of critical sewer system components within the collection system and establishing criticality ratings for these components. All data was compiled to formulate a long term rehabilitation and corrective action plan that includes an implementation schedule and estimates of probable costs.

The content and structure of the SSES program and report format has been established by the City. The City has provided guidance and general direction to the sewershed consultants to assure that all tasks completed in support of this study are prepared in a standardized format to facilitate the collection and review of the data for compliance with the requirements of the CD. Each of the eight (8) sewersheds in the City will be studied with emphasis on the inspection of sanitary sewers 8-inches and larger in diameter, including all sewer structures per Paragraph 9 of the CD. This information will be used in the preparation of a comprehensive corrective action plan for the sewershed. The City of Baltimore contracted with ADS/JMT A Joint Venture to complete the study of this Sewershed.

The sewers inspected per the CD ranged in size from small 8-inch diameter collector sewers to large 99-inch diameter interceptor sewers. The High Level Sewershed is comprised of four regions: Upper Gwynns Run, West Baltimore, High Level Siphon and Eastern High Level. Wastewater from Northwest portion of the HLSS drainage area is collected by the Gwynns Run Interceptor (GRI), which in turn, joins the larger High Level Interceptor (HLI) at the south end of the GRI. The HLI runs from west to east receiving flow contributions from the HLSS in the upstream reach, and from the Jones Falls and Low Level Sewersheds in the downstream reaches. The HLI joins the Outfall Interceptor at the beginning of Outfall Sewershed, and the Outfall Interceptor eventually conveys flow to the Back River Wastewater Treatment Plant (WWTP) for treatment. There are no permanent pump stations within the HLSS service area.

During the HLSS field investigations outlined in this section of the High Level Collection System Evaluation and Sewershed Plan no Sanitary Discharges of Unknown Origin (SDUOs) have been found.

4.2 Manhole Inspections

Manholes are the principal means to access a collection system. As such, effective manhole inspection is important in characterizing the overall condition and connectivity of the collection system. The manhole inspections completed for this project typically served multiple roles, which included characterizing the condition of the structure, identifying system connectivity, assisting in defining the general condition of the sewer segments connected to the structure, providing defect observation data required for the condition assessment and development of subsequent repair recommendations for the structure, and identifying additional potential sources of Inflow and Infiltration (I/I) into the collection system. The inspections also provided updated system attribute data such as pipe diameters, structure type and depths, network connectivity, and sewer system configuration. Collection of this data during the detailed inspections also allowed the City's GIS to be updated accurately and efficiently. These updates included removing structures that were originally identified as sewer structures in the GIS system but were actually not, and accurately updating the GIS with newly identified sewers and sewer structures that were not originally shown in the GIS.

Manholes were inspected as required by the CD in accordance with general guidelines outlined in the Environmental Protection Agency's (EPA) SSES Handbook, the American Society of Civil Engineers (ASCE) Manhole Inspection and Rehabilitation Manual 92, and the newly defined requirements of the National Association of Sewer Service Companies (NASSCO) Manhole Assessment and Certification Program (MACP). For the safety of the crews, the majority of manholes were inspected using a remote infrared manhole inspection camera to view and record defect images and observations in lieu of manned-entry to complete the majority of the inspections. The infrared manhole inspection camera used for the inspections allowed the inspector to visually observe the complete interior of the manhole or structure, including all incoming and outgoing pipes, and clearly identify defects. Generally, manned entry was performed on manholes greater than 20 feet in depth and/or manholes with barrel offsets and other unique configurations. When these were conducted, all entries were carried out in accordance with OSHA's 29 CFR 1910.146 Confined Space Entry Requirements. All inspections were completed under the guidance of MACP certified inspectors. Manholes that could not be located for inspection were documented for additional action. These structures will be inspected and incorporated into the City's overall rehabilitation plan.

To standardize the collection of the manhole inspection data, the High Level Sewershed Team used the City recommended Manhole Inspection Application Software (MIAS). MIAS allowed field crews to collect detailed inspection information about the physical characteristics of a manhole or structure, identify any sewer connections to the structure and record details about the environment surrounding the manhole that was needed to accurately characterize the condition of the manhole or structure. In addition to the characteristics of the structure, such as the structure's size, shape and construction material, the MIAS application allowed defects and potential sources of I/I to be recorded. MIAS was designed to provide internal methods that link the inspection photographs of the manhole or defect observations to the manhole database record, making them available for easy review and preparation of formal reports to the City or for review at a later date. MIAS also allows access to the GIS and aerial maps, which provided the inspector with additional system or location information in the field to allow them to accurately complete the inspection and update the detailed inspection database.

The following is a brief description of the process involved in the collection of manhole inspection data for the High Level Sewershed. The following descriptions are not intended to cover all aspects of the work performed, rather to provide the reader with a general understanding of the data collection and review process.

- A manhole inspection crew consisting of 2 inspectors uses a 1" = 100' scale GIS map to identify manholes to be inspected. This map contains information such as street names, manhole location and ID, flow direction and connectivity of the system with all other upstream and downstream manholes.

- The crew selects a manhole from the database list of manholes and goes to the location where the manhole is shown on the GIS map and locates the manhole or structure for inspection. If found, the manhole is located utilizing RTK survey grade GPS and then the manhole is inspected. If the manhole is not found, the crew will search an area 25 feet in radius from the estimated position based on the surrounding objects shown on the map.

- If a manhole structure is not found after field investigation or cannot be opened, it is noted as "Cannot Locate (CNL)" or "Cannot Open (CNO)" in the MIAS database. The CNL manholes are forwarded to the HLSS engineering and GIS teams where records research and recent CCTV inspections are used to determine if a manhole exists or not. If the CNL manhole does exist, it is documented as a Cannot Access (CNA) manhole and is added to a list given to the City for future action. If the CNL manhole does not exist, it is removed from the GIS and any further consideration. CNO manholes are given to a subcontractor on the HLSS Team capable of opening difficult manholes. Once the manhole is made accessible, the inspection team is notified and they revisit the site and complete the inspection.

Access to manholes on railroad property without an on-grade road crossing is prohibitive. The railroad company, CSX, has a time consuming process to execute access agreements and to schedule railroad staff to observe outside contractors performing work on railroad property. Among other factors, access couldn't be granted in time for HLSS Study completion. The HLSS has five inaccessible manholes in CSX railroad property. However, the HLSS was able to CCTV through each manhole from a manhole outside the railroad right-of-way and each of the five manholes appears to be in good condition. The HLSS Team recommends that the City should establish a process to gain access to sewer assets located in railroad property on short notice. This includes locating and uncovering buried manholes. See Map 4.2.1 that shows these five locations. Table 4.2.4 contains the inspection status of each manhole located in CSX right-of-way.

- Access to manholes on Maryland Transit Administration (MTA) property (Metro Subway and Light Rail) was a simpler process. The HLSS Team was able to perform a standard manhole inspection on manholes along the Light Rail on Howard Street by calling MTA 24-hours in advance and performing the work after trains stopped at 1 am. Manholes adjacent to the Metro Subway were a significant distance from operating trains/tracks and were approached from adjacent City streets. Many of these manholes were not accessible because they were either buried or covered by stockpiles of railroad rail and ties. However, these manholes were verified to exist and were inspected via CCTV inspection. In addition, the manholes near the Metro Subway are in good condition because they are part of the Gwynns Run Interceptor and were rehabilitated under Paragraph 8 project SC807. See Map 4.2.1 that shows the locations of MTA property manholes. Table 4.2.4 contains the inspection status of each manhole located in MTA right-of-way.

- Once a manhole is located and opened, the MIAS survey is completed. The format of the MIAS inspection form prompts the inspector to begin their inspection by recording features such as the structure's location, then features and defects are recorded starting at the top of the manhole structure and working down to the invert. These entries include frame/cover type, condition, and materials of construction for the chimney, corbel, barrel, bench and channel and their current condition and evidence of I/I.

- Photographs are obtained and entered into the system for location views and top down views of the manhole; photographs are also collected for the pipe connections and any significant defects when possible.

- Pipe sizes are recorded and located according to clock position with the outgoing pipe always being the 12 o'clock position. Pipe diameter and rim to invert depths are also collected and recorded in MIAS along with the condition of the pipe seals.

- In addition, a table of confirmed storm-sanitary sewer cross-connections discovered during manhole inspections is recorded in Table 7.3.1. These cross connections are applied to the hydraulic model. If the cross-connection becomes active during a storm intensity equal to or less than a 2-year storm frequency, it will be eliminated as part of the projects recommended in Section 7.

- All manholes are then assigned a 1-5 condition rating, with 1 being in excellent condition and 5 being in very poor condition and requiring immediate attention.

As the means for prioritizing the maintenance and repair of the manholes, a condition rating scale was used to weigh the various types of structural defects and I/I conditions that occurred in different components of the manhole structure. This rating system also allowed for the characterization of operation and maintenance (O&M) type issues such as identification of fats, oils and grease (FOG), debris accumulations, surcharging of the manhole and other O&M type issues. During the initial phase of this project, NASSCO introduced a standard for manhole condition assessment. This standard was the Manhole Assessment and Certification Program (MACP), which was subsequently adopted by the City to aid in the consistency of data collected and to provide for a reliable evaluation of each manhole component. The use of this standard provides a baseline condition assessment of the structure, which aids in providing a consistent review of conditions during future inspections. The 1-5 condition rating standard used for the manhole inspections is largely based on the

ASCE Manual of Practice No. 92, which utilizes a 5-point severity rating system. The following represents the rating scale:

1. **Excellent Condition –** Only minor defects
2. **Good Condition –** Defects have not started to deteriorate
3. **Fair Condition –** Moderate defects that will continue to deteriorate
4. **Poor Condition –** Severe defects likely to become a grade 5
5. **Immediate Attention Required –** Defects requiring immediate attention

Table 4.2.1 provides an overview of the condition of the 4,809 manholes inspected as part of the High Level manhole inspection program and classifies the manholes by overall structure rating. Table 4.2.2 provides an overview of the general defect locations within the manhole and Table 4.2.3 summarizes the total number of defects observed, classifying the conditions by defect type. Attachment 4.2.1 contains all manhole inspection reports completed for this project.

Table 4.2.1 – Manhole Condition Summary

Overall Rating	Count	%
1: Excellent Condition	24	0.50%
2: Good Condition	1578	32.81%
3: Fair Condition	2810	58.43%
4: Poor Condition	386	8.03%
5: Immediate Attention Required	11	0.23%
Manholes Inspected:	4809	

Table 4.2.2 – General Manhole Defect Summary

Count	Percent	Description
4809		Total Manholes Inspected
3959	82.32%	Manholes that Leak
165	3.43%	Frame Leaks
3517	73.13%	Chimney Leaks
1088	22.62%	Corbel Leaks
427	8.88%	Barrel Leaks
82	1.71%	Bench Leaks
57	1.19%	Channel Leaks

Table 4.2.3 – Manhole Defect Location Summary

Manhole Inspection Defects	
Component	**Quantity**
MH Cover Defects	284
MH Frame Defects	169
MH Chimney Defects	4,361
MH Corbel Defects	1,477
MH Barrel Defects	535
MH Bench Defects	1247
MH Channel Defects	516
MH Pipe Defects	2,640
Pipe Seal Defects	1,614
MH Steps	3,384
Total Defects:	16,227

Table 4.2.4 – Railroad Property Manhole Condition and Inspection Status

Manhole ID	CCTV Inspection	Manhole Inspection	Not Inspected	Property Owner	Condition Assessment
S09GG1019MH	X			MTA-Metro	Good condition, no serious pipe defects
S15EE_028MH	X			CSX	Infiltration evidence, Good structural condition, no serious pipe defects.
S15EE_011MH	X			CSX	Infiltration evidence, Good structural condition, no serious pipe defects.
S19CC_012MH	X			CSX	Good condition, no serious pipe defects
S19CC_007MH	X			CSX	Good condition, no serious pipe defects
S15OO_003MH	X			CSX	Good condition, no serious pipe defects
S13AA1006MH	X			MTA-Metro	Good condition, no serious pipe defects
S13WW_005MH	X			MTA-Metro	Rehabbed Pipe, Manhole in good condition
S13UU_001MH	X			MTA-Metro	Rehabbed Pipe, Rehabbed Manhole
S13UU_030MH	X			MTA-Metro	Rehabbed Pipe, Manhole in good condition
S33CC_027MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound
S33CC_005MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of debris on the bench, structurally sound
S33CC_047MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound
S33AA_022MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound
S33AA_019MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound
S33AA_005MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound
S33AA_018MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound
S33AA_017MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound
S33A__032MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound

Manhole ID	CCTV Inspection	Manhole Inspection	Not Inspected	Property Owner	Condition Assessment
S33A__014MH		X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound
S33A__015MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound
S33A__030MH	X	X		MTA-Lightrail	Rated as "Good" in MIAS, structurally sound
S33C__028MH	X			MTA-Lightrail	Good condition, no serious pipe defects, broken cover observed.
S33C__048MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS, structurally sound
S33C__001MH	X	X		MTA-Lightrail	Rated as "Fair" in MIAS because of corroded steps, structurally sound

4.3 Sewer Cleaning and Closed Circuit Television Inspection

Closed-circuit television (CCTV) inspection of sewers is the process of internally inspecting and documenting the condition of conveyance pipes. It provides valuable insight into the cleaning and maintenance requirements of each sewer segment. CCTV inspection also provides information that is needed to assign appropriate rehabilitation technologies to deteriorated or damaged sewer segments. A sewer segment is defined as the pipe between two manholes. In some instances, a sewer segment lies between a dead end and a manhole. The size of the pipe does not affect the PACP coding system. However the size of the pipe is taken into account in the High Level Sewershed Study criticality and condition rating tool which is the basis for overall study improvement project recommendations. The condition and criticality tool is discussed further in Section 7.1 herein.

Sewer Cleaning: All sewers inspected were cleaned prior to inspection to provide the highest visibility of defects. Sewers were cleaned utilizing hydraulically propelled high-velocity jetters or other mechanically powered equipment. The intent of the cleaning operation was twofold. First, to adequately clean the sewer so the inspection could identify defects that otherwise would not be visible, and second, to remove all foreign materials from the sewer to restore the sewer to a minimum of 95% of its original carrying capacity. Cleaning of the sewers was emphasized since it directly affected the success of the other phases of work. When significant restrictions, such as roots or other heavy debris, were encountered, heavy cleaning was utilized to restore the capacity of the sewers and to allow for internal inspection. Heavy cleaning involved root cutting or additional passes of the hydro-cleaning equipment. All debris was removed from the sewers and disposed of in a municipal waste facility. When significant blockages were identified, they were reported to the City, and the City promptly coordinated with the wastewater maintenance division or their on-call contractor to resolve the deficiencies.

Sewer Inspection: Following cleaning, the sewer segments were inspected by means of CCTV inspection. These inspections were used to identify the following:

- Current pipe condition, including existing or potential structural deficiencies or problems, and accurately identifying the pipe's connectivity and location.
- Confirmation, extent, and current condition of previous rehabilitation projects and/or repairs.
- Identifying improper or potentially illicit connections.
- Identifying potential sources and extent of segment I/I.
- Assist in selecting appropriate methods of repair, rehabilitation and/or replacement.

Paragraph 9 of the CD requires that gravity sewers eight (8) inches and larger in diameter be inspected using CCTV inspection in accordance with NASSCO guidelines. The CCTV inspection of the sewers provided the necessary condition assessment for the SSES evaluation of the High Level Sewershed. The inspections identified defects and other problems relating to the sanitary sewer collection and conveyance system that allows the project team to compile a comprehensive corrective action plan and prioritize an implementation schedule.

All CCTV inspection and data collection were completed according to NASSCO's Pipeline Assessment and Certification Program (PACP) guidelines and standards. The City required the use of PACP certified software to collect and record all CCTV information. All CCTV operators, equipment, and members of the review team were certified in the use of the PACP coding system.

All CCTV inspections were conducted using a color pan-and-tilt, radial viewing inspection camera that provided adequate illumination to clearly observe defects and other features within the pipe. All surveys were initiated from the upstream manhole proceeding downstream with the flow to minimize splashing of the camera. When defects or other obstructions prevented the completion of the inspection in this direction, a reverse inspection was initiated from the downstream manhole to complete the inspection of the sewer segment. The CCTV camera lens was required to be positioned in the center of the pipe being inspected and movement of the camera through the sewer pipe did not exceed a speed of 30-feet per minute. Wastewater flows in the sewer during the inspection were controlled and did not exceed 20 percent of the pipe capacity for pipes 8"- 10"; 25 percent for pipes 12"- 24", and 30 percent for pipes 24" and larger per the PACP guidelines. During the internal inspection, the CCTV camera was temporarily stopped at all significant defects and side sewer or service connections to accurately code and provide a clear image of the defect or point of connection. For larger sewer inspections where it was not practical, or when flows could not safely or effectively be reduced, sonar inspection or a combination of sonar and CCTV inspection was used to inspect the sewers. The use of a combination CCTV/sonar camera allowed for the visual inspection of the sewer above the flow line and the sonar provided inspection information below the flow of the sewer.

As a means to prioritize the maintenance and repair of sewer pipe sections and other associated sewer appurtenances, a condition rating scale was used to rate the various types and degrees of structural defects and I/I conditions occurring in different segments of the sanitary sewer system. The PACP rating scale was utilized as a standard and consistent format for the way pipes were evaluated and conditions recorded. These standards allow pipe conditions to be reported in a uniform recognized manner and allow the City to compare the segment's condition from one time frame to another and accurately track the condition of the pipe and any progression of defects. The PACP coding system requires the assignment of a specific code for each structural and O&M type defect identified within a pipe segment. The software automatically assigns a PACP rating code to each defect when entered. These grades are assigned based on the potential for further deterioration or possible failure of the pipe.

The PACP grading system obtained from NASSCO's "Pipeline Assessment and Certification Program" reference manual utilized for this project is as follows:

Grade	Description	Time to Failure
5	Immediate Attention Required	Pipe has failed or will fail within 5 years
4	Poor	Pipe will probably fail within 5 to 10 years
3	Fair	Pipe may fail in 10 to 20 years
2	Good	Pipe unlikely to fail for at least 20 years
1	Excellent	Failure unlikely in the foreseeable future

By utilizing this system, each pre-defined defect or observation code is directly associated with a severity rating based on the type and extent of the defect. The severity rating is not affected by the pipe size, only the actual defects present in the pipe. These ratings aid in determining the need for maintenance, repair, rehabilitation or replacement of the sewer segment. The PACP software assigns a four-digit severity code, or PACP quick rating, for each sewer segment inspected and contained in the database. These ratings, in conjunction with the critically rating, which takes the pipe size into account, were used to prioritize system repairs.

Table 4.3.1 summarizes the defects recorded during the CCTV inspections by type of defect. Table 4.3.2 summarizes the defects by overall segment condition rating. Table 4.3.3 summarizes the O&M conditions. Attachment 4.3.1 is an Access database that contains all CCTV inspection information completed as part of the CCTV inspection program in the High Level Sewershed.

Table 4.3.1 – CCTV Defect Observation Summary

CCTV Inspection Defects		Pipe Size (inches)					Total
Family	**Group Type**	**8”-12”**	**14”-18”**	**20”-33”**	**36”-56”**	**>60”**	
Structural	Break in Pipe	3,035	59	30	24	0	3,148
Structural	Collapse	62	3	0	0	0	65
Structural	Cracks	22,921	531	315	177	369	24,313
Structural	Defective Joints	8,865	36	14	0	0	8,915
Structural	Defective Lining	95	162	66	0	0	323
Structural	Deformation	214	21	22	10	0	267
Structural	Hole	765	4	42	11	15	837
Structural	Fracture	8,906	191	116	88	0	9,301
O&M	Encrustation	1,814	150	351	1,094	1,009	4,418
O&M	Grease	4,392	112	83	154	0	4,741
O&M	Infiltration	686	237	421	625	262	2,231
O&M	Obstruction	1,490	54	17	19	7	1,587
O&M	Roots	17,114	168	90	22	33	17,427
O&M	Settled Deposits	2,467	90	147	226	0	2,930
Constructional	Break-in Taps	823	37	90	254	442	1,646
Constructional	Line Deviations	1,774	58	103	188	148	2,271
Constructional	Camera Underwater	170	16	9	6	19	220
Constructional	Survey Abandoned	1,189	53	18	4	6	1,270
	Totals	**76,782**	**1,982**	**1,934**	**2,902**	**2,310**	**85,910**
	Percentage of Total	**89.37%**	**2.31%**	**2.25%**	**3.38%**	**2.69%**	

Table 4.3.2 – Sewer Structural Condition Rating Summary

Rating	Pipe Segments	
5 - Defects that require immediate attention	153	2.7%
4 (Poor) – Severe defects that will become grade 5 in the near future	98	1.7%
3 (Fair) - Moderate defects that will continue to deteriorate	82	1.4%
2 (Good) - Minor defects that have not started to deteriorate	422	7.3%
1 (Excellent) – No defects or minor defects present	4,997	86.9%
Total:	5,752	

Table 4.3.3 – Sewer Operation and Maintenance Condition Rating Summary

Rating	Pipe Segments	
5 - Defects that require immediate attention	159	2.8%
4 (Poor) - Severe defects that will become grade 5 in the near future	236	4.1%
3 (Fair) - Moderate defects that will continue to deteriorate	297	5.2%
2 (Good) - Minor defects that have not started to deteriorate	703	12.2%
1 (Excellent) - No defects or minor defects present	4,357	75.7%
Total:	5,752	

4.4 Smoke Testing

Smoke testing was utilized by the HLSS Team as a cost-effective method of locating system defects and sources of inflow and infiltration in the sanitary sewer collection system. Smoke testing can identify inflow sources that are directly connected to the sanitary system including footing or foundation drains, roof drains or leaders, downspouts, drains from window wells, outdoor basement stairwell drains, driveway drains, sump pumps, cross-connections between storm and sanitary systems and even streams. Smoke testing also reveals indirect connections that allow groundwater to enter the sanitary system through physical defects in the pipes or manholes.

Smoke testing in the High Level Sewershed was performed between August 2008 and September 2009 on dry days when the ground was not saturated or frozen. A minimum waiting period of 24 hours following a rain event was used so that the ground would be sufficiently dry to allow smoke to travel through the soil when testing resumed. All pertinent local officials including the City Police Department, City Fire Department, 311, and the City Department of Public Works were notified prior to the start of smoke testing. The residents in the areas to be smoke tested were notified about the testing via flyer and door hanger. Advanced notification allowed residents with special requirements to inform the HLSS Team before the testing was done so that the necessary arrangements could be made. Two to four weeks prior to testing, flyers were distributed to the residents/owners of all residences and businesses within a two block radius of the test locations. Follow-up door hangers were delivered to residences and businesses two to three days before testing.

The smoke testing was conducted by placing one or more gas-powered blowers over centrally located manholes and forcing a harmless, non-toxic smoke into designated sections of the sanitary sewer. Sandbags were used to retain smoke within the test section. A maximum of 1,000 LF of sewer pipe per blower was tested in a single test set-up to ensure that smoke filled all of the sewer main and connected laterals. The field crew was responsible for verifying that smoke reached the entire test area by observing smoke from roof vents along the test section. Smoke was continuously injected into the sewer until the field crew had checked all buildings, surrounding grounds, and streets within the test area for signs of smoke.

Information about smoke observations was recorded on field forms and field maps. In addition, at least one photograph was taken of each smoke observation. Suspected direct or indirect connections between storm drains and sanitary sewer pipes were recommended for follow-up dyed water flooding to confirm the existence of a cross-connection. Smoke observations from suspected private sector sources directly connected to the sanitary system were recorded on the field forms and maps but follow-up dyed water testing was not performed.

Table 4.4.1 summarizes the observations recorded during the smoke testing inspections by sector and by source type. Attachment 4.4.1 contains all smoke testing inspection data generated during this project.

Table 4.4.1 – Smoke Testing Observation Summary

Sector Code	Sector Description	Total Observations	%
01	Public	123	12
02	Private	941	88
	Total:		
Source Type Code	**Source Type Description**	**Total Observations**	**%**
01	Main Sewer	13	1
02	Service Line	162	15
03	Cleanout	739	70
04	Downspout	18	2
05	Area Drain	5	1
06	Driveway Drain	3	0
07	Stairwell Drain	2	0
08	Foundation Drain	3	0
09	Building Interior	1	0
10	MH Frame Seal	15	1
11	Storm Drain	0	0
12	Catch Basin/Inlet	76	7
13	Storm Manhole	3	0
14	Storm Ditch	0	0
15	Excavation	0	0
16	Other	24	2
	Total:	1064	

Observations that were coded per Table 4.4.1 as 12 – Catch Basin/Inlet or 13 – Storm Manhole were scheduled for additional investigation utilizing dyed water flooding.

4.5 Dyed Water Testing

Dyed water tests were conducted by the HLSS Team to confirm potential I/I sources that were first identified through smoke testing. Dyed water testing is a method of locating and quantifying sources of clear water in the sanitary sewer system. Given the number of catch basin/inlet defects identified during smoke testing, the HLSS Team decided to conduct dye flooding tests exclusively. .

Dyed water testing in the High Level Sewershed was performed in April 2009 on dry days when the ground was not saturated or frozen. Flooding dye tests were used to verify direct or indirect connections between storm drains and sanitary sewer pipes. During smoke testing, if smoke was observed being emitted from a catch basin, storm manhole, or other storm feature, the observation was recorded for subsequent dye testing to confirm the suspected source. The flooding dye test was conducted by flooding the suspected source with dyed water and plugging the storm pipe downstream of the source to trap the dyed water. If dye was observed in the sanitary sewer downstream of the suspected source, then the source was confirmed as being either directly or indirectly connected to the sanitary sewer. A waiting period of at least one hour after the introduction of dye into the storm manhole or catch basin was used before a flooding dye test could be considered negative.

Dyed water tracing was used in conjunction with the flooding dye tests. Dyed water tracing utilizes CCTV inspection equipment to determine the exact location where I/I enters the sanitary sewer. After dye was observed in a downstream manhole, a CCTV camera was used to televise the sanitary sewer pipe upstream from that manhole. The CCTV inspector noted any location at which dye entered the sanitary sewer pipe or manhole through a defect. Information about dye observations was recorded on field forms and field maps. In addition, the CCTV inspector took at least one still photo of each dye observation.

Of the 12 dye flooding tests performed in the High Level Sewershed, 10 tests confirmed locations of clear water entering the sanitary sewer. These positive dye tests indicated locations of indirect connections. These indirect connections result from stormwater leaking out of the storm drain and into the sanitary sewer through sewer or lateral defects (e.g. trench migration of stormwater), typically where the two systems cross one another. Each manhole or a sewer segment associated with a positive dye test is recommended as a priority repair in Section 7 of this study.

Previously unknown direct connections were discovered in High Level and were large enough to verify connectivity by CCTV inspection. These direct connections are listed in Table 7.2.1.

Table 4.5.1 summarizes the observations recorded during the dyed water testing inspections by sector and by source type. Attachment 4.4.2 contains all dyed water testing inspection data generated during this project.

Table 4.5.1 – Dyed Water Testing Observation Summary

Sector Code	Sector Description	Total Observations	%
01	Public	35	100
02	Private	0	0
	Total:	35	
Source Type Code	**Source Type Description**	**Total Observations**	**%**
01	Main Sewer	0	0
02	Service Line	0	0
03	Cleanout	0	0
04	Downspout	0	0
05	Area Drain	0	0
06	Driveway Drain	0	0
07	Stairwell Drain	0	0
08	Foundation Drain	0	0
09	Building Interior	0	0
10	MH Frame/Seal	0	0
11	Storm Drain	0	0
12	Catch Basin/Inlet	29	83
13	Storm Manhole	6	17
14	Storm Ditch	0	0
15	Excavation	0	0
16	Other	0	0
	Total:	35	

As shown in Table 4.5.1, public storm drain, inlets and manholes were verified as indirect sources of sanitary sewer inflow during the dyed water testing.

4.6 Priority and Emergency Repairs / Rehabilitation

In accordance with the requirements of Paragraph 9 C (iii) of the CD, which states “Identify all rehabilitation or other corrective actions taken by Baltimore (including but not limited to grouting, point repairs, liner replacement) to address the deficiencies identified during evaluation of the sewershed.”

In support of this effort, the HLSS Team reported all significant system defects observed during field inspections or when reviewing the collected data as part of the sewer evaluation phase. Upon discovery of these deficiencies, the information was compiled and detailed maps, CCTV video and photographs were provided to the City for action. In some cases the City’s non-emergency assistance hotline (311) was also contacted.

The resolution of the work was prioritized based on on-going repair work being performed within the City and the severity of the deficiency discovered (emergency or priority). Emergency maintenance issues are severe situations, such as major structural defects, that may present a public safety hazard or result in a sanitary sewer overflow or sewer leak. Priority maintenance issues need prompt repair in order to avoid an emergency situation. These issues include, but are not limited to, heavy roots and grease and significant structural defects. As the City-wide evaluation survey continues, new deficiencies will be identified and reported to the City. To date the High Level Sewershed Team has identified 68 priority repair locations. Figure 4.6.1 shows the spatial locations of these priority repairs.

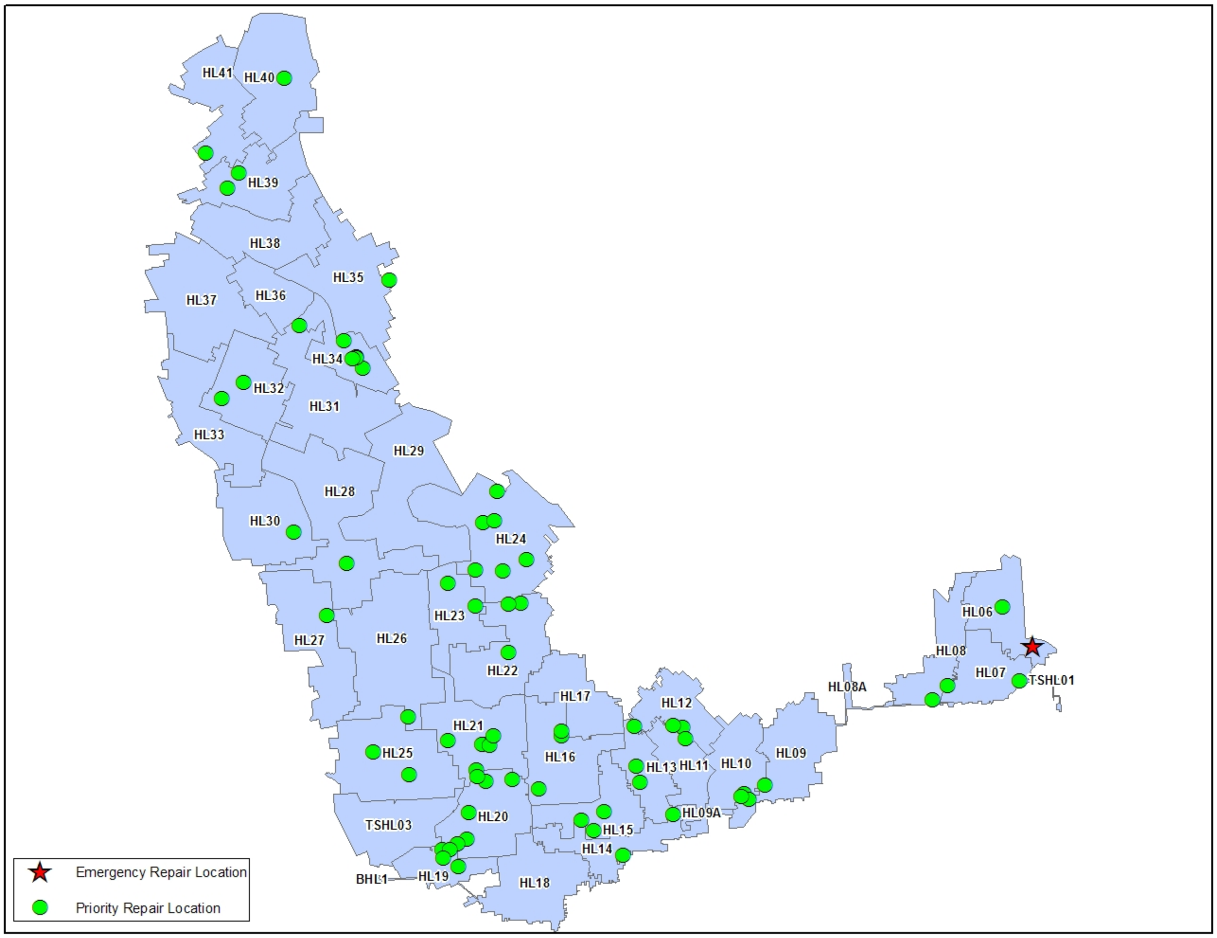


Figure 4.6.1-High Level Sewershed Priority Repairs Found as of September 2009

4.7 Pumping Station Evaluations

The HLSS does not contain sanitary sewer pump stations. The Jones Falls Pump Station force main/pressure sewer and several of its abandoned predecessors cross the HLSS but are not evaluated as part of the HLSS study.

4.8 Quality Assurance / Quality Control Procedures

The following sections provide the reader with a brief description of the Quality Assurance / Quality Control (QA/QC) review process that all inspections underwent before they were considered complete and delivered to the City. In addition, copies of the Manhole Condition Rating and Defect Manuals, CCTV Review Manual and Smoke and Dyed-Water Testing Procedures Manuals developed by the HLSS Team to insure the consistency and accuracy of the data being provided to the City are included as Attachments 4.8.1 through 4.8.4 of this report.

4.8.1 Manhole Inspection QA / QC Procedures:

MIAS contains several internal field checks, which prompt the inspector to verify information as it is entered. (e.g.: if an inspector enters the invert elevation of an outgoing pipe at a higher elevation than the incoming pipe's invert elevation, the check prompts the inspector to verify the information). Several of these internal checks will not allow the inspector to move on to the next entry item in the inspection until the prior inspection item has been successfully completed.

Basic information regarding location and system connectivity was compared with existing information or contract documents. Connecting manhole nodes entered in MIAS were compared to what was shown on the mapping and corrections made as necessary.

All information was reviewed, which included reviewing for errors, assuring photograph quality and reviewing all comments entered by the inspector for clarity and content.

If there was information missing, the MIAS record was failed and returned to a field crew to revisit the site and collect the required information or the reviewer would utilized existing record documents to obtain the required information.

When the follow-up information was collected by the field crew or addressed by the reviewer utilizing record data, the new information was again reviewed and if acceptable, added to the record. The record was then tagged as QA/QC complete and flagged for submittal to the City.

4.8.2 CCTV Inspection QA / QC Procedures:

All CCTV inspections were reviewed for conformance with PACP coding guidelines (video quality, flow levels, header information, all defects coded, and coded properly).

Review all CCTV footage and inspection logs for significant defects such as collapsed pipe, blockages, etc. and forwarded these defects to the City for action.

Review CCTV footage and inspection logs for significant O&M items such as excessive grease, roots, etc. and forwarded these defects to the City for action.

If issues were found with video quality or PACP coding of defects for the segment inspected, the inspection record was returned to the CCTV contractor with review comments for recoding or re-surveying.

4.8.3 Smoke Testing QA / QC Procedures:

All completed field reports were reviewed for conformance to the project guidelines and accuracy assuring that all maps, defect information and photographs are complete, clear, accurate and compatible.

Review all smoke testing entries entered into the Access database to assure all observations and photographs are in accordance with the database scheme and specifications outlined for the project.

If any field data collected was questionable, incomplete or illegible, the data was returned to the responsible contractor with review comments for correction and resubmission.

Review all data submitted to identify significant defects such as cross connections. Any significant findings were reviewed and if required, assigned for further evaluation utilizing dyed-water testing.

Any confirmed cross connection, major defects or illegal connection must be submitted to the City for follow up action are documented in the Seweshed Plan and Study Report.

4.8.4 Dyed-Water Testing QA / QC Procedures:

All completed field data was reviewed for conformance with the project guidelines and accuracy requirements assuring that all maps, defect information and photographs are complete, clear, accurate and compatible.

All dyed-water testing information was entered into the Access database to assure all observations and photographs are in accordance with the database scheme and specifications outlined for the project.

If any field data collected was questionable, incomplete or illegible, the data was returned to the responsible contractor with review comments for correction and resubmission.

Any confirmed cross connection, major defects or illegal connection must be submitted to the City for follow up action are documented in the Sewershed Plan and Study Report.

5.0 HYDRAULIC MODELING

The technical consultant, 1015, has been charged with the responsibility of developing an overall city-wide model of the system (termed as the “regional/macro model”) by integrating all the sewershed models (termed as “micro models”) independently being developed by the eight consultant teams.

In accordance with the specifications in the consent decree (CD), the HLSS system micro-model included all the gravity and pressure sewers listed below:

- All sanitary sewers 10-inch and the larger in diameter;
- All 8-inch sewers necessary to accurately represent the hydraulic connectivity, where needed;
- All sewers connecting the pump station service areas; and
- All sewers that have historically contributed to capacity-related overflows and engineered SSO locations which were designed to alleviate localized surcharging/flooding until the rehabilitation projects under Paragraph 8 were completed.

In order to maintain consistency in technical approaches used by the eight consulting firms, the 1014 and 1015 teams have established guidelines in the Baltimore Sewer Evaluation Standards (BaSES) Manual. The overall approach is to build the model in accordance with the requirements outlined in the CD and calibrate/validate adhering to the guidelines provided in the BaSES manual. Long-term monitoring data compiled by the City was used to support this task; however, short-term additional flow monitoring was utilized in two situations where necessary to enhance understanding of the system. These include additional metering of the High Level Siphon to understand the head losses through this portion of the system and extended flow metering following the completion of the SC812 improvements as these Paragraph 8 improvements were not metered during the original monitoring period.

Specific modeling objectives for this study, as stated in Consent Decree, are to evaluate the impact of the following:

- I/I rehabilitation projects,
- Proposed system modifications,
- Upgrades, and
- Expansions to the transmission capacity and performance of the collection system.

The City selected InfoWorks CS as the uniform modeling software for characterizing the sewer systems and conducting citywide I/I studies. Specific guidelines provided in the BaSES manual were used to select appropriate modeling parameters in the InfoWorks suite and assess the model calibration adequacy. Per BaSES Manual requirements, the most current version of InfoWorks was used throughout the model construction, calibration/validation and application of the model to evaluate the current sewer capacity, estimate the extent of I/I, and to conceptualize I/I rehabilitation strategies for certain design storms and select the appropriate and cost-effective alternatives.

The hydraulic model development and calibration are further detailed in the Baltimore High Level Sewershed Model Development and Calibration Report, which is included in Attachment 5.2.1.

5.1 Model Network

Data acquisition is a critical step in the development of a hydraulic model. In this step, the data pertaining to a study area is obtained from various available sources either to characterize the sewershed for constructing a model network and developing model parameter values, or to provide a basis for evaluating the model performances.

In order to build a model network, physical information of structures in a sewer system (manholes, pipes, diversion chambers, weirs, gates, pump stations, etc.) are necessary. Digitized pipe network databases in GIS compatible format have become largely available for a large number of municipalities in the U.S. Additional information including paper drawings, field inspection reports, and operational records are used to supplement and improve the existing digital databases. New technologies like CCTV survey can provide up-to-date information on structural damages or obstructions in the pipes.

For computing wet weather flow generation from each drainage area, characteristic data such as drainage area size, land-use and land-cover, percent imperviousness, ground contours, and soil types need to be obtained. Also needed are the meteorological and hydrological data such as rainfall, evaporation, infiltration rate, and depression storage.

Historical hydraulic data (flow, water level, and velocity) are necessary for model calibration and validation to ensure that the model can well represent the sewer system bottlenecks or surcharging observed in the field. For sanitary sewer systems, historical SSO occurrence records and sewer backup/basement flooding complaint data can be very useful for evaluating how the model simulates the events occurred in the past.

Any monitored data must undergo a thorough review and quality control before they can be used in the model. Data in good quality and quantity reduces the model uncertainty and enhances robustness of the model in representing the real-world hydraulic conditions. Various statistic tools and procedures can be used to perform the data quality check, and this process is often integrated with the process of data analysis for developing model inputs.

Model network construction begins with setting up the nodes (manholes) and links (e.g., pipes, force mains, and pump stations) that simulate the real-world physical pipe network connectivity. In the next step, the drainage area must be segmented to subcatchments as smaller hydrology calculation units. Subsequently, initial values of parameters for pipe network and drainage subcatchments need to be populated based on data compiled so far.

In a sanitary sewer system, the total flow consists of several components (as illustrated in Figure 5.1.1): base ground water infiltration, waste water production including sanitary flow from residential areas and waste flow from industrial dischargers, and RDII flow during wet weather periods. Except for the RDII flows, the quantity and time variation patterns of each flow component need to be developed for each contributing drainage area and distributed throughout the model network based on their connection points to the sanitary sewer system. The model's wet weather flow generator is adopted to calculate RDII for the given rainfall data and subcatchment parameters. Boundary conditions, such as inflows from connecting sewersheds, WWTP plant headwork, or tidal influences at outfalls, need to be compiled and provided as external time-series input into the model.

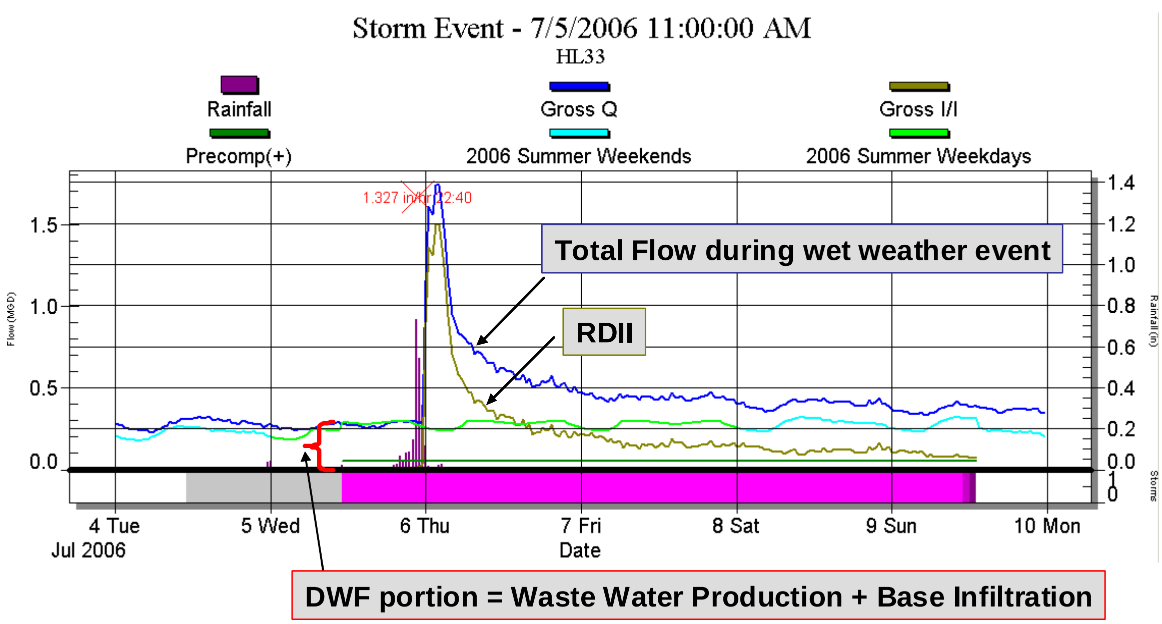


Figure 5.1.1 – Flow Components in Sanitary Sewer System

5.2 Model Calibration

Subsequent to construction, the model needs to be calibrated and validated using historical data. This process consists of two steps: dry weather calibration and then the wet weather calibration.

Dry weather calibration ensures that the model representation of the dry weather flow components (base infiltration and waste water production, along with any significant dischargers) is accurate before the more complex RDII is introduced during wet weather calibration. This process is conducted based on selected time-periods in the historical flow monitoring with several continuous dry days with no influence from the antecedent soil moisture. By checking the flow, water depth and velocity at a number of locations in the sewer system, the quantity, time variation and allocation of the dry flow components can be appropriately defined from the various contributing drainage areas and refined, if needed. Following this process, the wet weather calibration focuses on simulation of RDII reaching the sanitary sewers.

In order to enhance the robustness of model performance, wet weather calibrations are conducted based on a variety of rainfall events with different patterns in terms of the event volume, intensity and duration. Appropriate calibration parameters are adjusted to optimize the matching of modeled and monitored data for wet weather volume, peaking and the time-to-peak for the hydrographs at all or most of the metering locations. Statistical tools are also used to the overall adequacy of model calibration.

When the model calibration is completed, the same parameters are used in simulating a few independent dry and wet weather events. This constitutes a model validation process, which is used to confirm that the model can be used for conditions different from those used for model calibration. Model validation, in essence, enhances the model robustness for application to future conditions including capacity analyses using the design storms.

The accuracy and performance of a computer model is best measured by its ability to reproduce the actual system performance that it is designed to simulate. Model calibration and validation is a process of adjusting appropriate model parameters to achieve the desired accuracy of model reproduction of the observed historical events.

A calibration and validation process first involves a selection of several simulation periods (events) for which data is readily available or has been collected. It is important to select periods that are also representative of the conditions that will be simulated by the model such as either typical or extreme rainfall events, or both, in addition to normal and/or seasonal dry weather conditions. Several periods can be selected during a calibration process such that model parameters are chosen and adjusted to reasonably reproduce actual data within acceptable and justifiable model parameter ranges. The calibration process can result in several sets of model parameters that may reasonably simulate individual events, but may need to be combined to simulate different future conditions that the model will be used to analyze. Therefore, validation periods are simulated once a set of model calibration parameters has been selected. The accuracy and performance of the model can then be assessed by its ability to independently simulate validation events without adjusting any model parameters. If the model performance for validation periods is not within acceptable tolerance levels, model calibration will need to be repeated with the selection of a different set of parameters, with further validation to enhance its robustness.

The data collected at flow meters installed during the city-wide monitoring program were used to evaluate the modeling results. The following methods suggested in BaSES were adopted for evaluating the model calibration/validation results and determining the adequacy of calibration for application to future baseline and alternatives analyses:

- Time series comparisons of observed and modeled dry and wet flows, velocities and water depths
- Statistical goodness-of-fit plots of observed and modeled wet event peak flows and volumes

Dry Weather Calibration Summary

The two components of the dry-weather flow (DWF), average waste water production (WWP) rate and groundwater base infiltration (BI), were first quantified during model calibration using Sliicer.com a City approved online inflow and infiltration analyzer developed by the ADS Environmental, Inc. Figure 5.2.1 shows the estimated average daily or base infiltration (or BI) for the HLSS. The BI evaluation was difficult for flow basins along the GRI and HLI for several reasons, including highly varying inflows from the upstream Ashburton Water Filtration Plant as well as smaller net flows of these basins relative to the total gross flow that the meters captured along the Interceptors. All the flow basins along the HLI and four flow basins along the downstream portion of the GRI were aggregated separately to quantify the BI component.

Sliicer.com analyses yielded average daily DWF hydrographs for each monitoring basin for both weekdays and weekends. This data was then used to develop hourly diurnal peaking factors. This was done by first subtracting BI from the hourly values of the DWF hydrographs and then dividing by the average WWP.

Six events were selected among the three seasons of study (Summer 2006, Winter 2007 and Summer 2007) for both pre and post-SC812 conditions to support the DWF calibration (refer to Table 5.2.1). The primary rationale for selecting those events was to choose dry periods with no rainfall for at least 48 hours prior to the event so that there would be little or no residual moisture that might affect infiltration during these periods. The duration of events ranged from 5 to 12 days in order to characterize the possible variations between the weekday and weekend water usage patterns, in accordance with the BaSES guidelines.

Table 5.2.1 – Dry Weather Flow Calibration Events

Event Number	Event Period	Season	Duration (days)	SC-812 in service
1	May 27-31, 2006	Summer 2006	5	No
2	August 11-22, 2006	Summer 2006	12	No
3	December 4-12, 2006	Winter 2006	9	No
4	February 5-13, 2007	Winter 2006	9	No
5	March 28-April 3, 2007	Summer 2007	7	Yes
6	April 30-May 10, 2007	Summer 2007	11	Yes

For dry weather, the pipe roughness was primarily used to calibrate the model for depth and velocity at each flow meter location. The adequacy of model calibration was assessed using time-series plots of simulated and observed flow, depth and velocity compared at each flow meter and the average flow rate on a system-wide basis. The model performance, in terms of the correlation between monitored and modeled data, was very good at most of the locations for flow rate, depth and velocity.

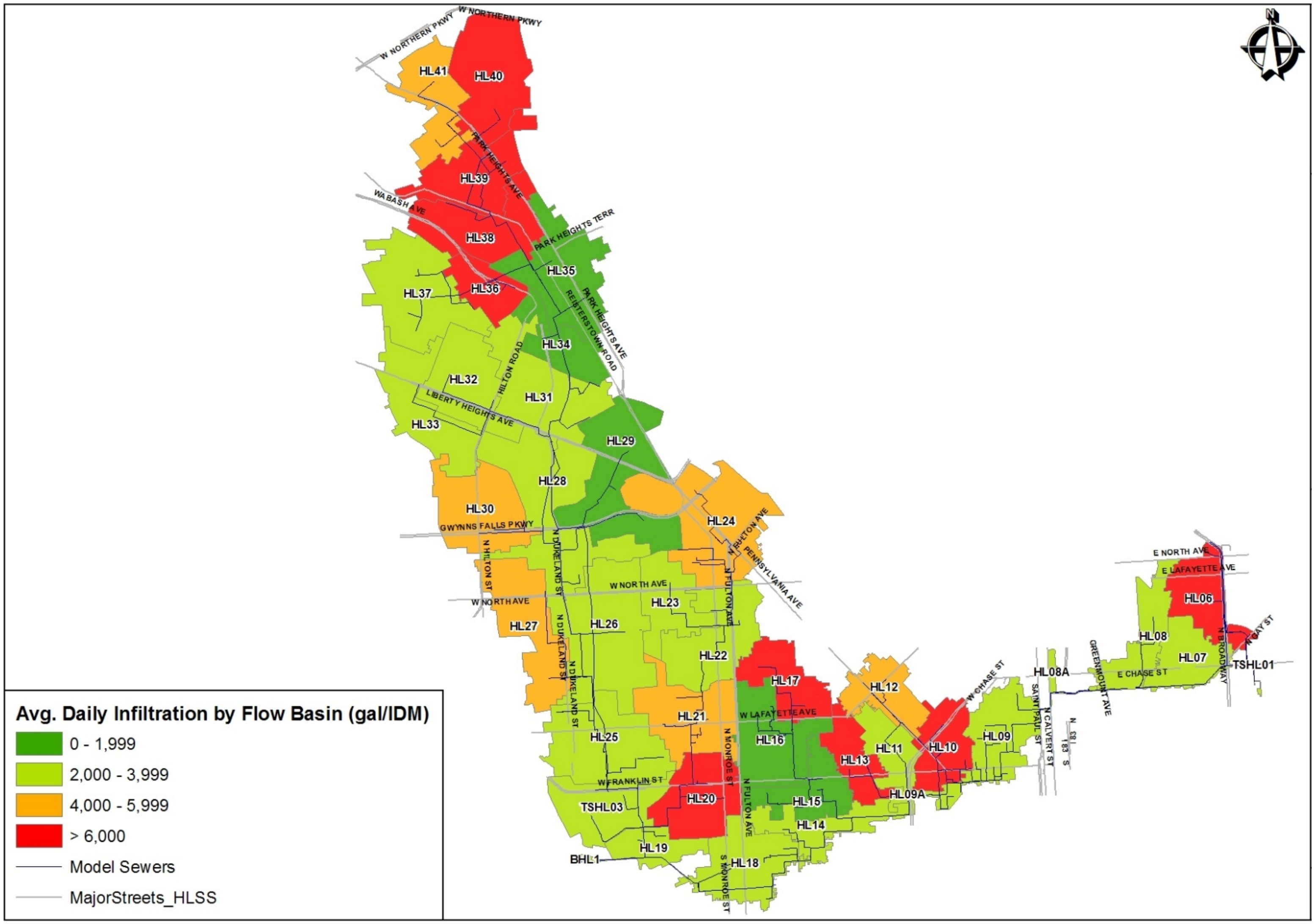


Figure 5.2.1 – HLSS Baseline Model Average Daily Infiltration

Wet Weather Calibration Summary

Prior to conducting the wet weather flow calibration, Sliicer.com was used to determine the RDII severity in HLSS. The severity was expressed in terms of a capture coefficient (R-value); which is defined as the fraction of rainfall volume that entered the sanitary system for a given total rainfall volume for each flow basin. The RDII quantification during wet weather in Sliicer.com is extremely challenging under one or more the following conditions:

(a) net basin flow is less than 20% of gross flow,
(b) boundary flow is significant, and
(c) irregular and undocumented pump station discharges.

In HLSS, the RDII severity could not be quantified for three flow basins (HL25, HL26, and TSHL03) along the GRI due to irregular and undocumented pump discharges from the Ashburton Water Filtration Plant and its Wash Water Lake. RDII also could not be accurately quantified for six flow basins (HL07, 08, 09, 14, 18, and 19) along the HLI due to their small net-to-gross flow ratios and the large boundary flows from the Jones Falls and Low Level sewersheds. For these interceptor flow basins, the R-values were initially determined based on the average value for a number of nearby HLSS basins and further adjusted during model calibration.

Except for the interceptor flow basins, the capture coefficient was calculated for both summer and winter seasons in Sliicer.com. Figure 5.2.2 shows the capture coefficient values for each flow basin. This Figure was color coded from light blue to dark blue based on the severity of I/I, as reflected by the increasing values of the capture coefficient. Two observations may be made based on the HLSS data analysis:

RDII was more severe for flow basins contributing to the upstream portion of GRI
RDII was more severe in winter than in summer for the entire HLSS

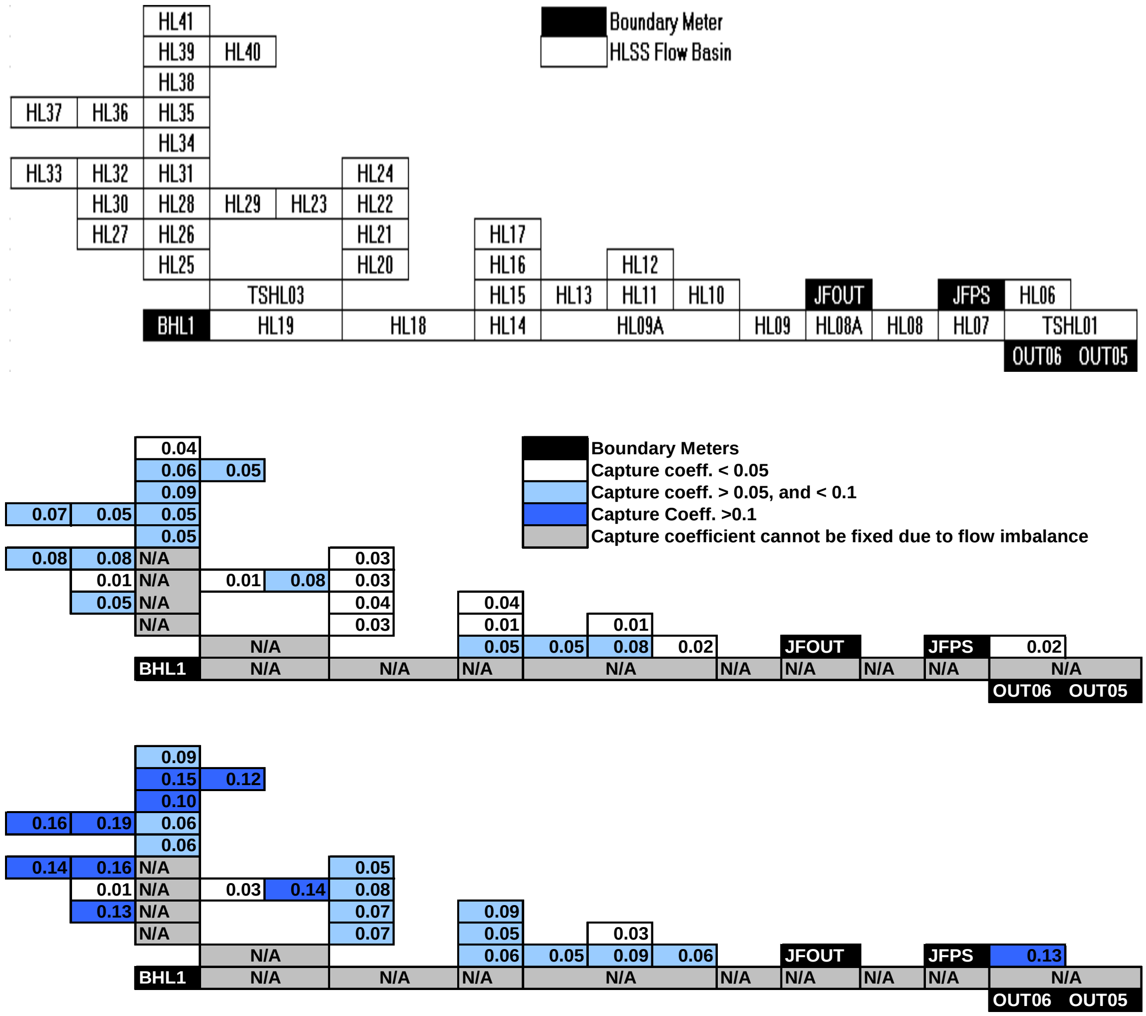


Figure 5.2.2 – Processed Summer (above) and Winter (below) Capture Coefficients in HLSS

In order to simulate wet weather flow the SWMM RUNOFF routine available within InfoWorks CS was used as a synthetic storm hydrograph generator. Simulating the rainfall-dependent infiltration and inflow (RDII) using SWMM RUNOFF requires the specification of catchment characteristics that result in correct estimation of the RDII. The parameters needed are: area, R-value, depression storage, width, slope, and an overland flow routing coefficient.

Wet weather flow calibration was conducted separately for the summer 2006, winter 2007, and Post-SC812 periods to reflect the significant seasonal RDII severity changes and the change due to the installation of a 30" relief pipe along the GRI (SC812). Calibration was conducted based on the 29 "global" storms for which the radar rainfall data were provided by the City. The runoff routing value was used as the primary calibration parameter to achieve the desired RDII volumes, while the catchment width and slope were used as supplemental parameters to achieve the desired time-to-peak and peak flow characteristics. Capture coefficient and depression storage, derived from Sliicer.com, were used as fixed parameters in the RDII analysis. Calibration results were reviewed using time-series plots for flow, depth, and velocity and evaluated using model calibration criteria suggested in BaSES manual.

In order to assess whether the calibrated model satisfied the criteria for each metered location, the HLSS team also evaluated goodness-of-fit plots to compare the simulated and observed values for peak flow, flow volume, peak depth, and peak time. Figure 5.2.3 shows an example of goodness-of-fit plots for flow meter HL07 located closer to the downstream end of the HLI. The calibration criteria for peak flow rate, volume, and surcharge depth are represented as grey dashed lines (on either side of the green 45-degree line that represents a perfect correlation between the two). This provides a visual check to assure that the model results meet the criteria for most of the storms.

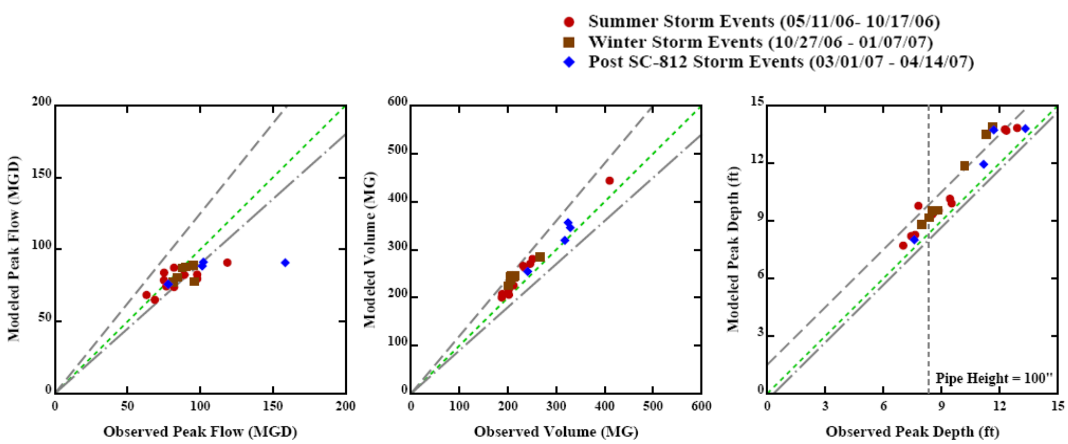


Figure 5.2.3 – Goodness-of-fit Plots at Flow meter HL07

The adequacy of wet weather flow calibration was assessed by the HLSS team using two additional metrics: historical SSO locations and maximum HGL. Two large storms, one on July 5th, 2006, and the other on November 16th, 2006, were selected from the monitoring period. The twenty-four hour intensity for both storms approximated a 2-year return frequency. The potential SSO locations revealed from the simulation results of these two storms were compared with the historical SSO locations. The simulated maximum HGLs along HLI were also compared with the observed data at each flow metering location. The model results correlated very well with observed data in the entire system.

Finally, the calibrated summer and winter models were combined into a unified model using the median-R capture coefficient as required by the City. Figure 5.2.4 shows the median R capture coefficient in the HLSS. The combined median-R model was further fine-tuned using several major global storms so that the model could also accurately represent the system behavior during intense storm conditions used for the baseline and alternative analysis.

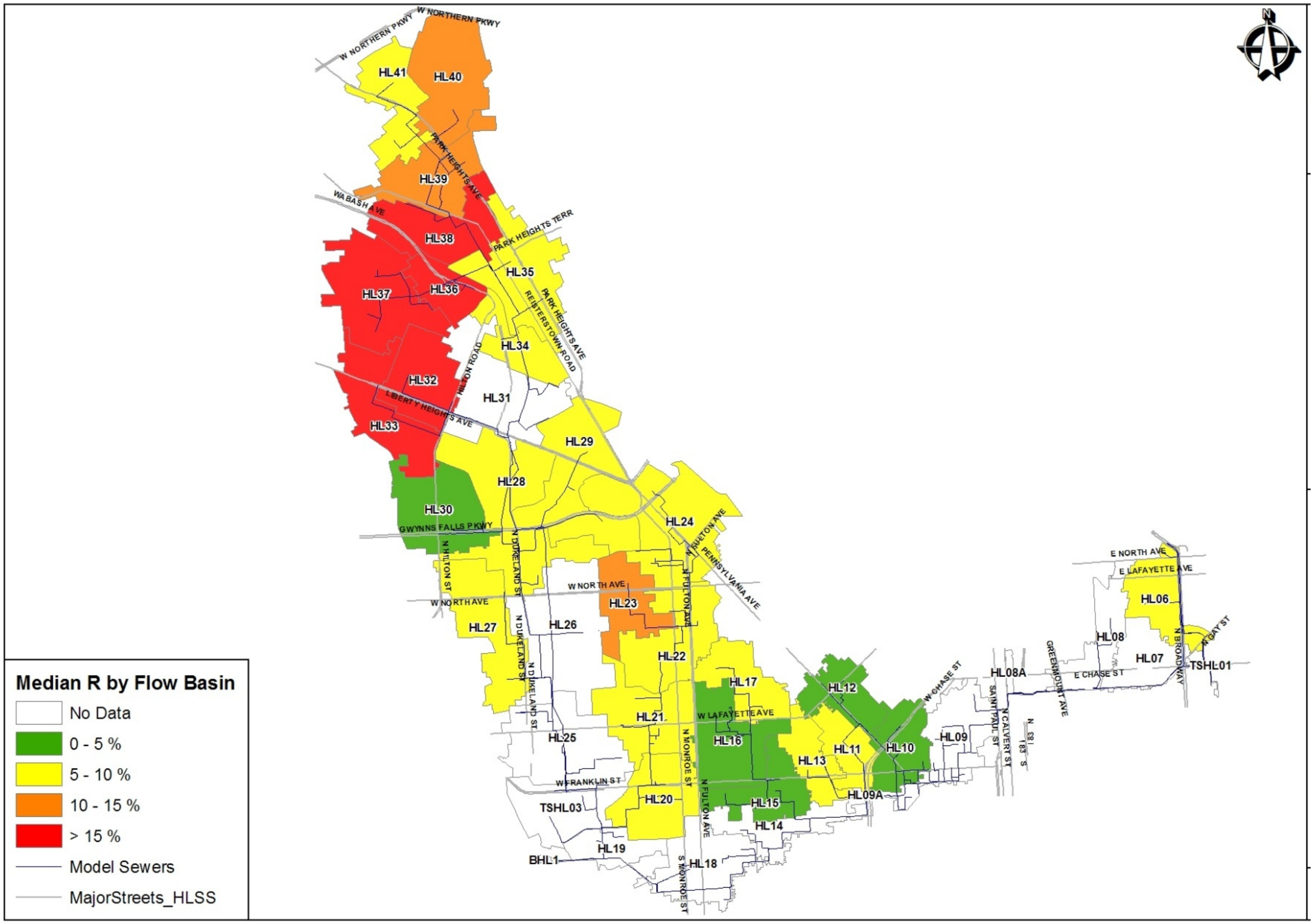


Figure 5.2.4 – HLSS Median-R Value Capture Coefficients

5.3 Baseline Analysis and Capacity Assessment

5.3.1 Design Storms

Seven design storms were analyzed to assess the sewer capacity limitations during wet weather periods. These design storms included a three-month storm with a duration equal to the time of concentration for the sewershed (2.5 hours for the HLSS) and 1-, 2-, 5-, 10-, 15-, and 20-year, 24-hour duration storms. The storm distribution chosen for analysis is the NOAA Atlas 14/NRCS distribution. The storm depths for the seven design storms are as follows:

Table 5.3.1 – Design Storms Rain Depth (inches) and Peak Intensity (inch/hour)

Design Storms	Rain Depth (inches)	Peak Intensity (in/hour)
3 – Month, 2.5-Hour	1.11	1.3
1 – Year, 24-Hour	2.67	2.2
2 – Year, 24-Hour	3.23	2.6
5 – Year, 24-Hour	4.15	3.2
10 – Year, 24- Hour	4.97	3.6
15 –year, 24-Hour	5.41	3.7
20 Year, 24-Hour	5.82	4.0

Figure 5.3.1 shows the hyetograph of the provided design storms along with the actual observed peak intensity of three major storms that occurred during the model calibration period as references. The peak intensities of 5-year and the larger storms are much greater than the peaks of existing storms used during model calibration. Thus, it can be concluded that the model was calibrated with up to 2-year design storm severity, and the baseline simulation results with 5-year and the larger events could have some uncertainties. However, those should be very useful to compare and select cost-effective SSO mitigation plans, considering the extensive model calibration involving over 40 meters and 29 global storms.

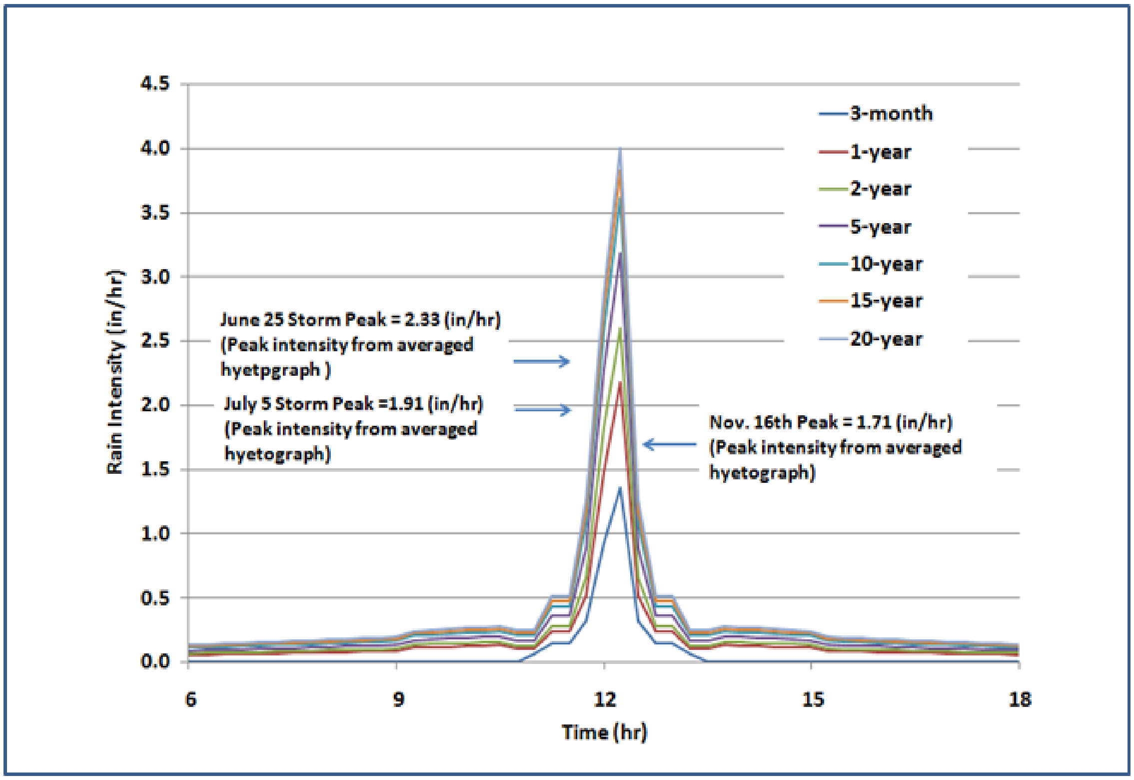


Figure 5.3.1 – Hyetograph of 3-Month, 1-, 2-, 5-, 10-, 15-, and 20-Year Design Storms

5.3.2 Definition of Deficiency

If SSOs occur, the system is defined as deficient; therefore, adequate capacity will be considered to be all flow maintained within the system, which may include surcharging.

5.3.3 Storm Simulations (All Storms)

One of the CD requirements is to run a Return Period Analysis (RPA) on the seven design storms. The InfoWorks' built-in RPA utility was used to compare the surcharge state in pipes and flooding results of the design storm runs in order to determine the minimum size storm required to surcharge or flood (cause an overflow) a pipe segment, along with the estimated flood volume. The results of the baseline flooding RPA are presented for each sub-sewershed in Figure 5.3.2 (Upper GRI), Figure 5.3.3 (Liberty Heights), Figure 5.3.4 (Lower GRI), and Figure 5.3.5 (West Baltimore and East HLI).

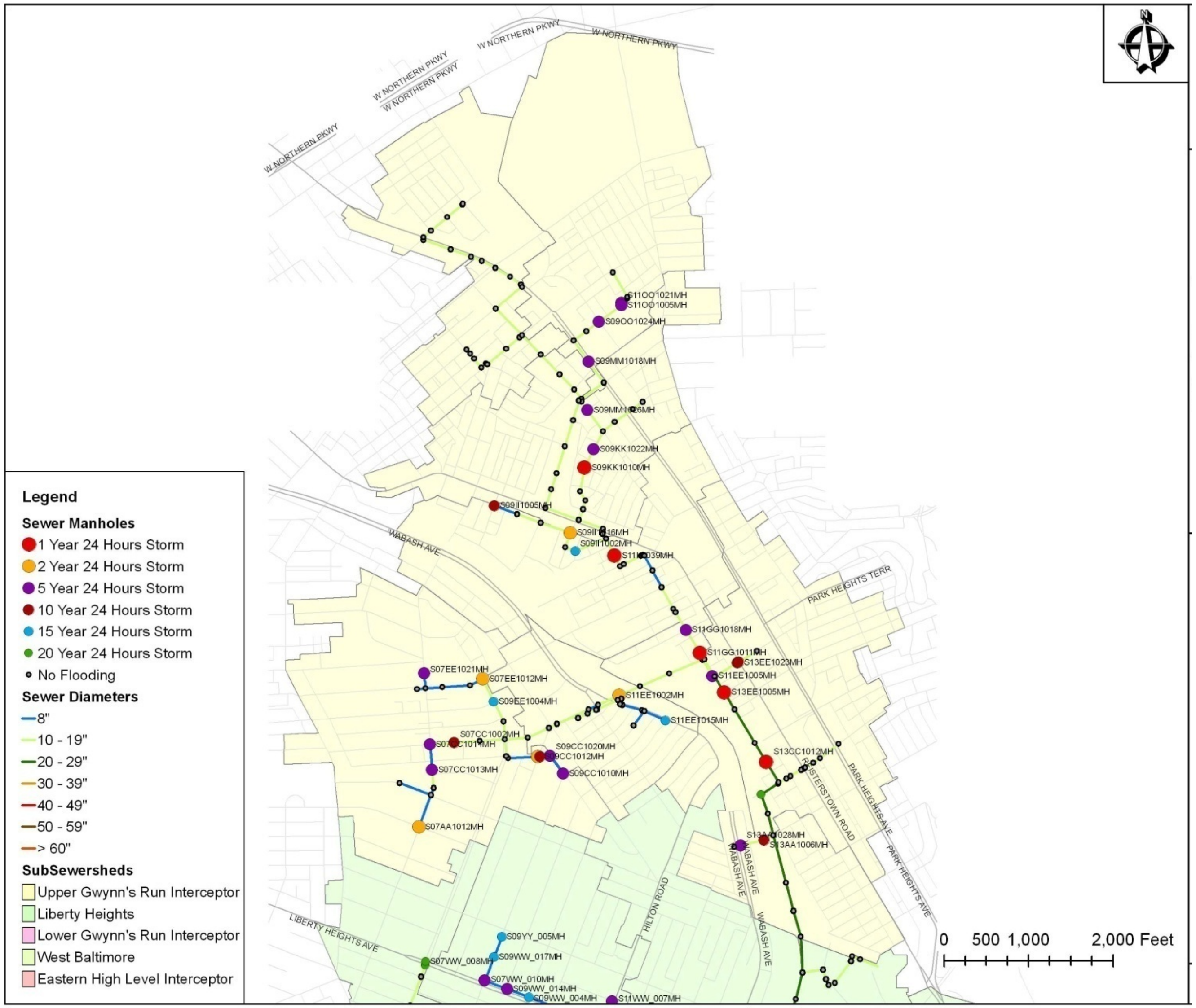


Figure 5.3.2 – High Level Baseline Flooding Return Period Analysis Upper Gwynns Run Interceptor

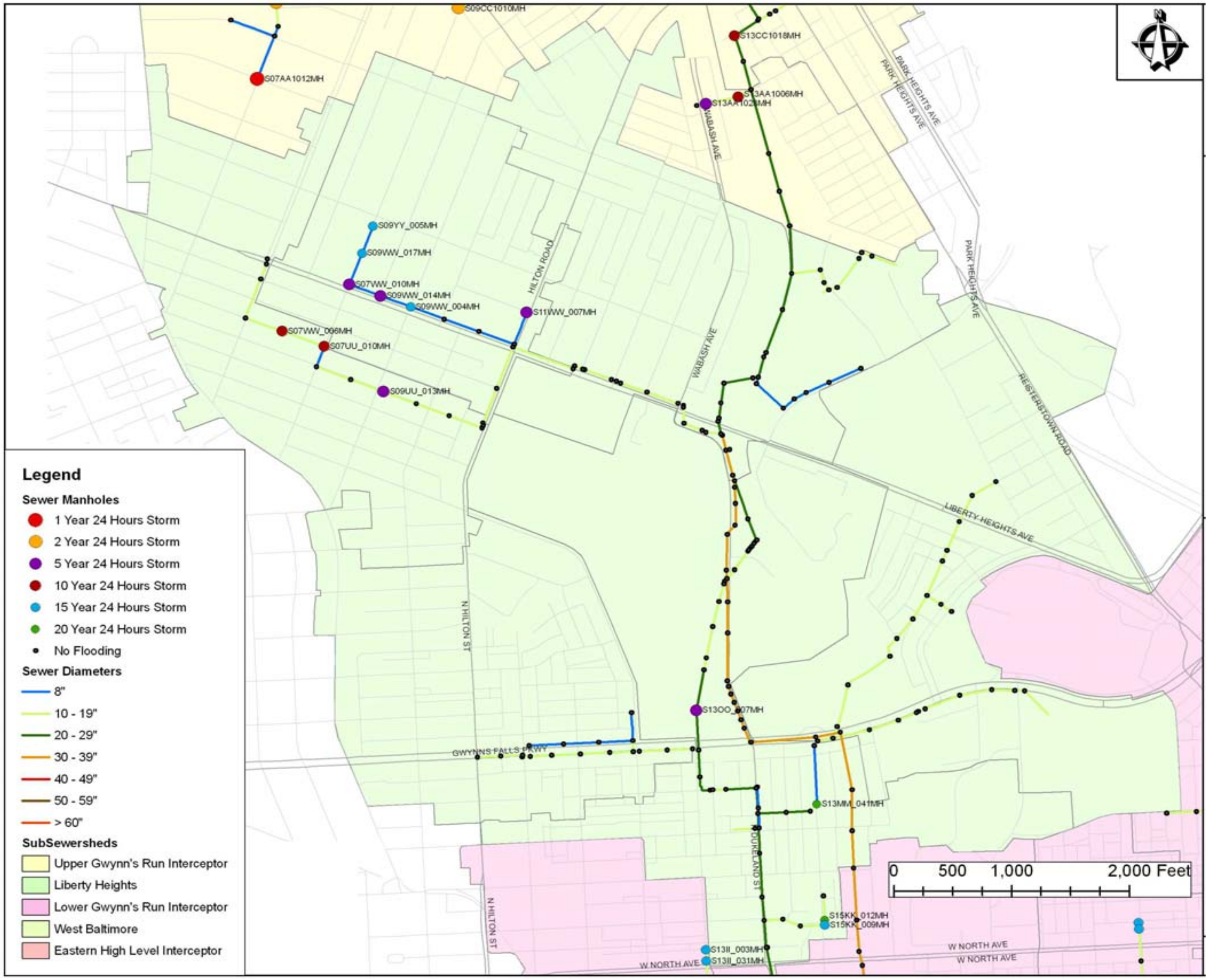


Figure 5.3.3 – High Level Baseline Flooding Return Period Analysis Liberty Heights Interceptor

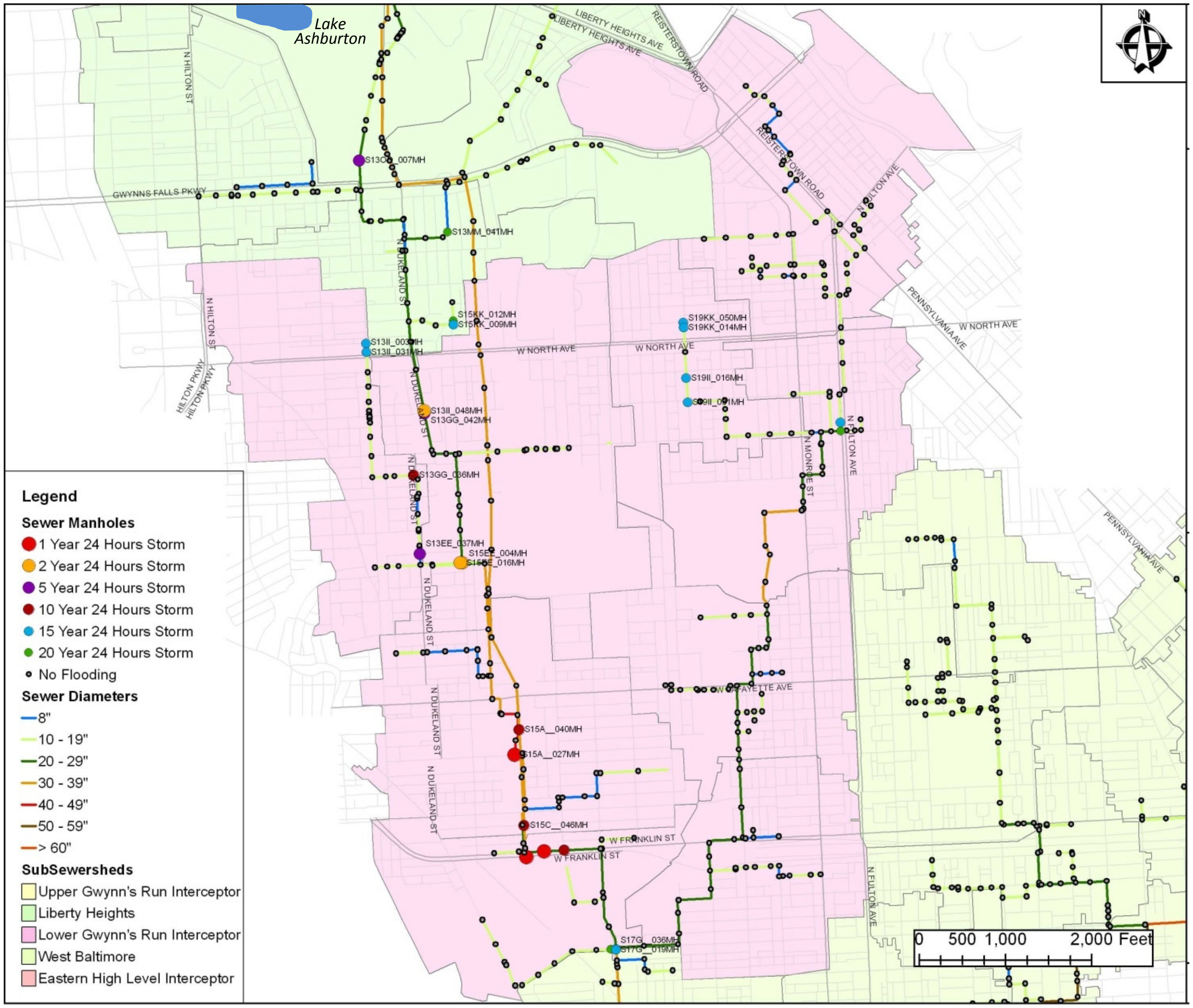


Figure 5.3.4 – High Level Baseline Flooding Return Period Analysis Lower Gwynns Run Interceptor

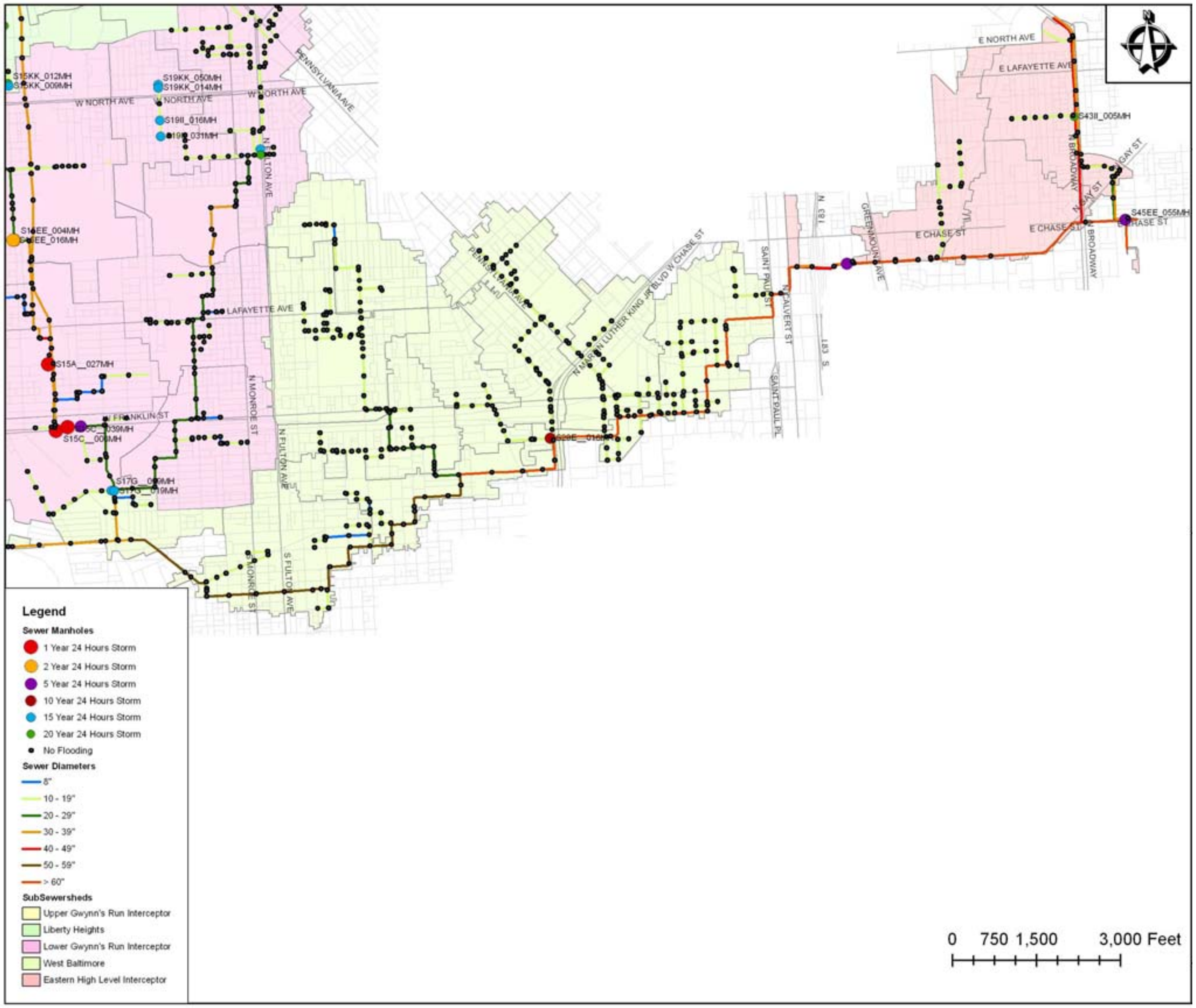


Figure 5.3.5 – High Level Baseline Flooding Return Period Analysis West Baltimore & East High Level Interceptor

Under the DWF and 3-month storm conditions, there are no SSOs in the HLSS; but the model has predicted SSOs for all the other storm conditions analyzed. Table 5.3.2 shows the total SSO volumes through the manholes and each remaining active engineered overflows for the 1, 2, 5, 10, 15, and 20-year design storms.

During the sewershed study, previously undocumented SSO's 138, 139, 140 and 141 were discovered and were modeled within the baseline model. Table 5.3.2 shows SSO overflow volume for different storm intensities (shown in italics in the table). Recommendations for the elimination of these SSO's is included in Section 7 of this report

Table 5.3.2 – Baseline SSO Volumes

Event	**Manholes (MG)**	**SSO132 (MG)**	**SSO134 (MG)**	**SSO135 (MG)**	***SSO138 (MG)***	***SSO139 (MG)***	***SSO140 (MG)***	***SSO141 (MG)***
3-Month, 2.5-Hour	0.00	0.00	0.00	0.00	*0.00*	*0.00*	*0.00*	*0.00*
1-Year, 24-Hour	2.89	0.13	0.12	0.00	*0.01*	*0.00*	*0.00*	*0.01*
2-Year, 24-Hour	5.72	0.34	0.18	0.00	*0.04*	*0.00*	*0.00*	*0.08*
5-Year, 24-Hour	10.05	0.70	0.25	0.00	*0.09*	*0.04*	*0.00*	*0.14*
10-Year, 24-Hour	14.15	0.98	0.31	0.00	*0.12*	*0.08*	*0.01*	*0.18*
15-Year, 24-Hour	16.43	1.13	0.33	0.00	*0.14*	*0.11*	*0.01*	*0.21*
20-Year, 24-Hour	18.43	1.26	0.36	0.00	*0.16*	*0.14*	*0.01*	*0.23*

Upper Gwynns Run Interceptor

Along the GRI, there are several flooded manholes caused by a 1-year storm. This is due to the high RDII severity in the area served and limited capacity of this interceptor relative to the large flows. Additionally, there are several overflow locations in HL36 and 37 for the 2-year storm.

Liberty Heights

There are only a few overflow manholes in HL32 and 33 areas resulting from large storms. However, there are three engineered overflow structures that remain active in this vicinity (i.e. SSO 132, 134, and 135) and they transfer a large amount of sanitary sewage into the storm sewers (Table 5.3.2). The details of these engineered overflows and alternatives to eliminate these three engineered SSOs are provided in the Alternatives Analysis Report.

Lower Gwynn's Run Interceptor

There are three overflow manholes for the 1-year design storm at both upstream and downstream of the confluence point of the 30" SC812 relief and the 32" GRI near Franklin Street because these two major sewer lines tie into the existing 27" GRI along Franklin Street. According to the original design, however SC-812 was supposed to extend all the way to the HLI, but the relief sewer was shortened due to construction challenges and financial constraints. Details regarding the modeling of the extended portion of SC-812 to check if the SSOs near Franklin Street can be eliminated are provided in the Alternative Analysis Report.

West Baltimore and Eastern High Level Interceptor

There is one overflow manhole in the West Baltimore area for the 15-year and 20-year storm. This manhole, adjacent to the HLI, floods when the HLI significantly surcharges. In the eastern HLI area, manhole S43EE_034M is a recurring SSO manhole in front of the Baltimore City Detention Center (BCDC) which relieves over 5 MG of SSO volumes for a 5-year design storm.

There are about 1,300 ft of 8" pipe segments along Hunter Avenue directly connected to the upstream diversion chamber of the High Level Interceptor triple-barrel siphon. One of the manholes in the section, S35CC_017MH, has experienced SSOs in the past.

5.3.4 Identification of Hydraulic Deficiencies (All Storms)

One of the CD requirements is to identify and map all components of the wastewater collection system which restrict the flow of wastewater that cause or contribute to or are likely to cause or contribute to overflows within the collection system. InfoWorks CS has a utility function designed to assist in determining such flow restriction sections in a sewer system. InfoWorks compares the slope of the HGL at peak flow in a sewer segment to its pipe slope. A surcharged sewer with a HGL slope steeper than the pipe slope indicates that the sewer is restricting flow, i.e., a bottleneck exists in this sewer segment. If the HGL is flatter than the pipe slope, then the surcharge is not necessarily caused by a capacity limitation in that pipe and the sewer segment could be under backwater conditions caused by a downstream control.

Figure 5.3.6 (Upper Gwynns Run Interceptor), Figure 5.3.7 (Liberty Heights), Figure 5.3.8 (Lower Gwynns Run Interceptor), and Figure 5.3.9 (West Baltimore and Eastern High Level Interceptor) depict the results of this analysis, which shows the smallest storm event during which the sewer's capacity became restrictive and led to overflows at upstream locations.

A summary of pipe sizes and cumulative lengths identified are shown in Table 5.3.3.

Table 5.3.3 – Baseline Restriction Length per Pipe Size and Storm Event

Diameter (in)	3-month	1-year	2-year	5-year	10-year	15-year	20-year
8" - 14"		5,359	7,512	10,806	12,532	13,029	13,605
15" - 29"	1,600	12,131	16,114	19,492	22,748	23,772	24,445
30" - 59"	863	3,193	4,227	5,390	6,708	7,141	7,141
>= 60"	4,739	7,918	8,527	9,120	10,036	10,036	10,410
Total (ft)	7,201	28,601	36,379	44,808	52,024	53,978	55,600

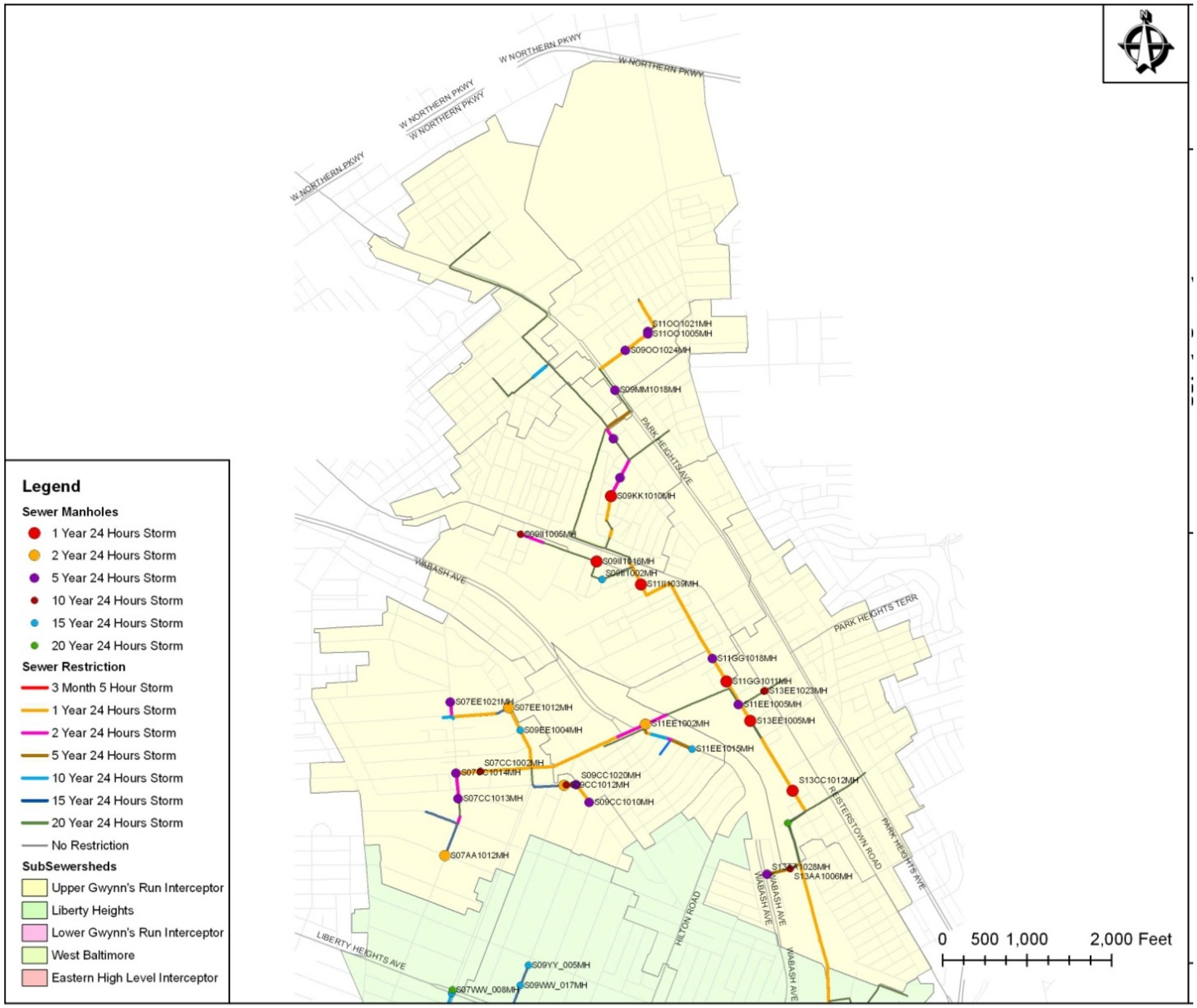


Figure 5.3.6 – High Level Baseline Hydraulic Restriction Analysis Upper Gwynns Run Interceptor

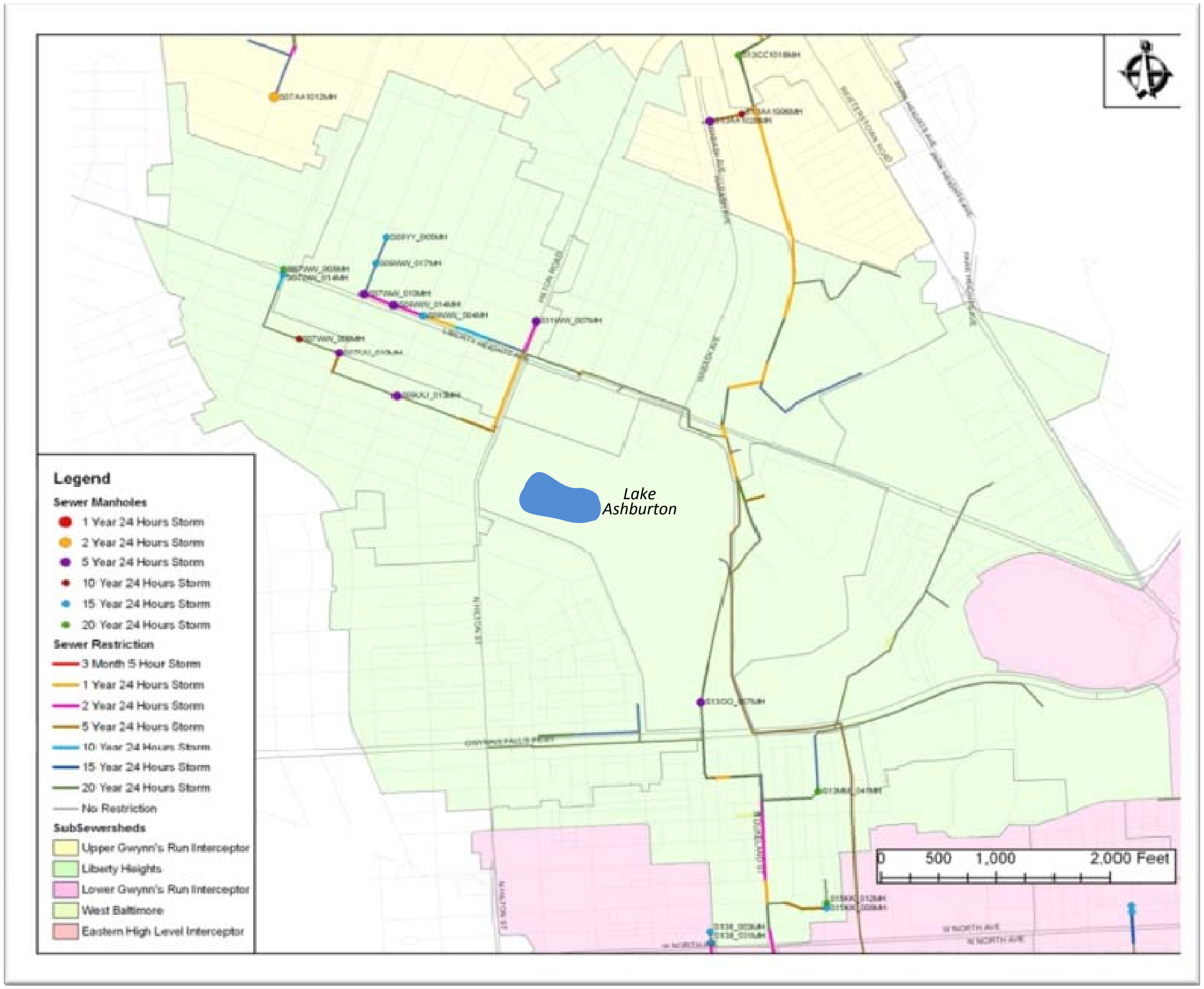


Figure 5.3.7 – High Level Baseline Hydraulic Restriction Analysis Liberty Heights Interceptor

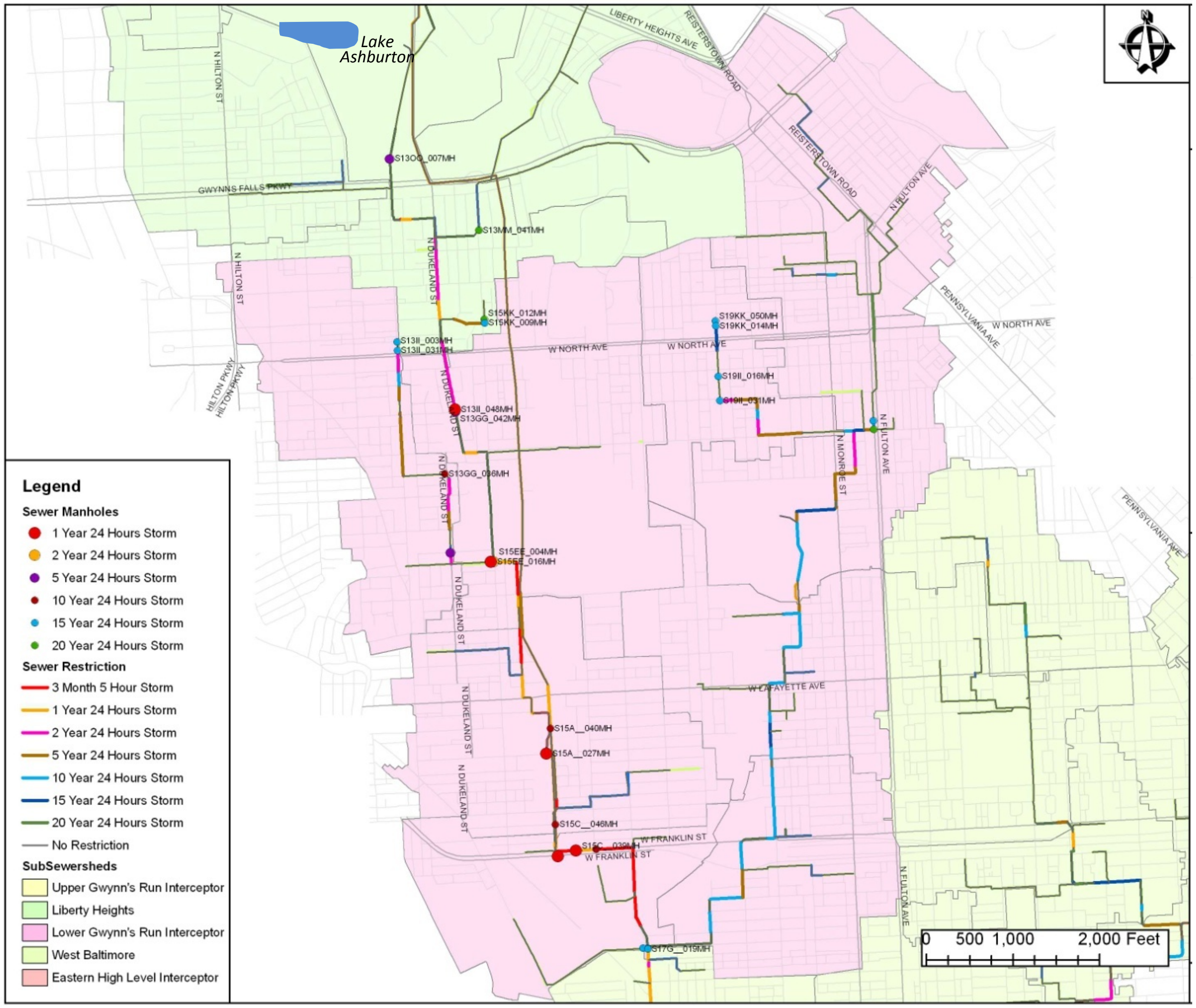


Figure 5.3.8 – High Level Baseline Hydraulic Restriction Analysis Lower Gwynns Run Interceptor

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DAVID E. SCOTT, P.E.
DIRECTOR

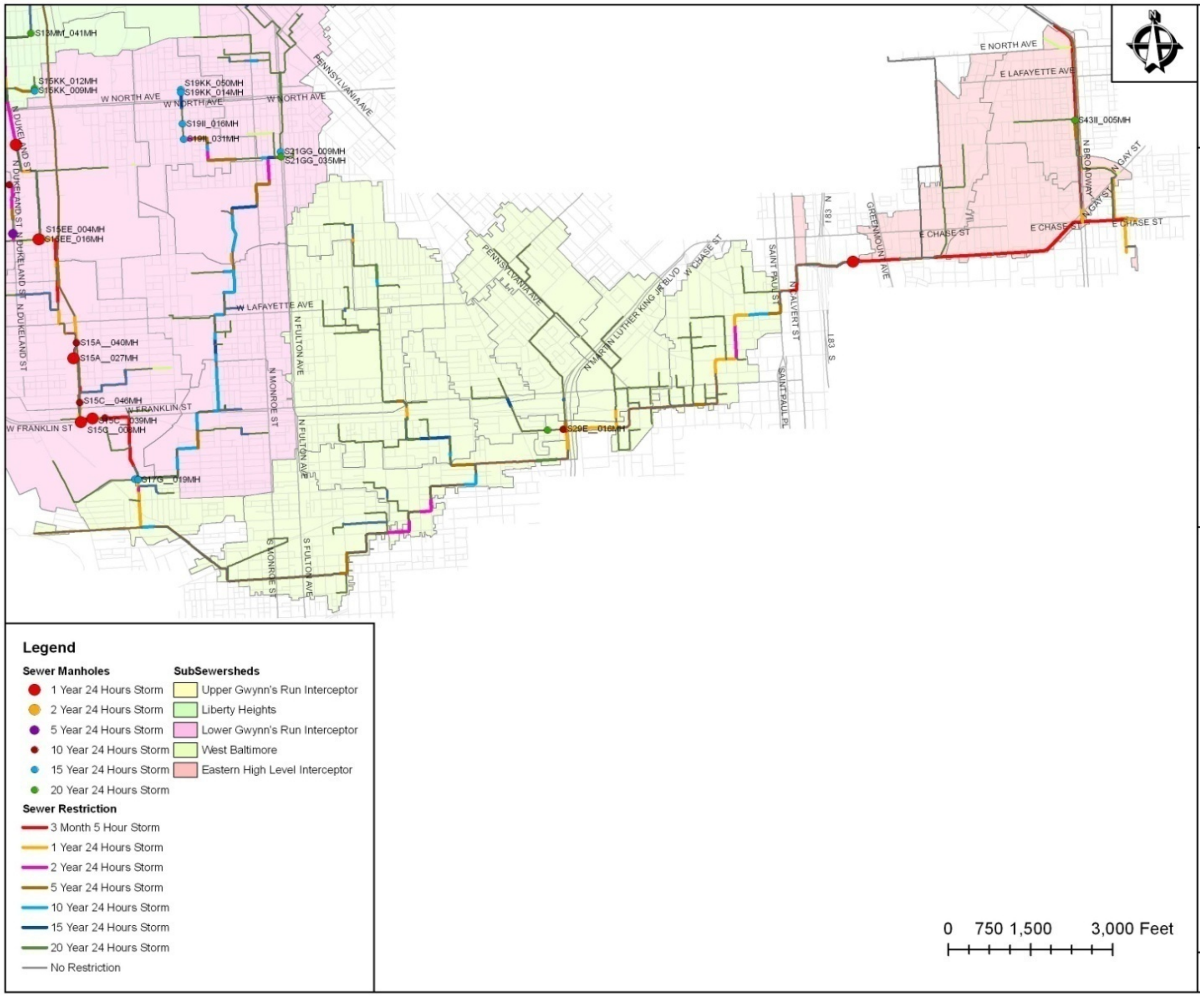


Figure 5.3.9 – High Level Baseline Hydraulic Restriction Analysis East High Level Interceptor

Based on the flow restriction analysis, the HLSS team identified three major locations in the HLSS where the sewer does not have adequate capacity. These three locations are described below with each sewer profile and the maximum HGL:

Upper Gwynns Run Interceptor

Figure 5.3.10 shows the maximum HGL along the Upper GRI for the 2-year design storm condition. The HGL gradually increases from the downstream end where the SC812 relief pipe provides adequate capacity, and the HGL reaches the ground level at S13CC_1018MH. The maximum HGL is near ground elevation until manhole S09MM1006MH, where the interceptor gained a steeper slope providing an increased velocity and subsequently additional flow capacity. As shown in Table 3.4.A, S11II1039MH has the highest SSO volume because the sewer has the lowest relative depth compared to the rim elevation nearby and the HGL exceeds the manhole rim elevation for the longest duration among the Upper Gwynns Run interceptor manholes.

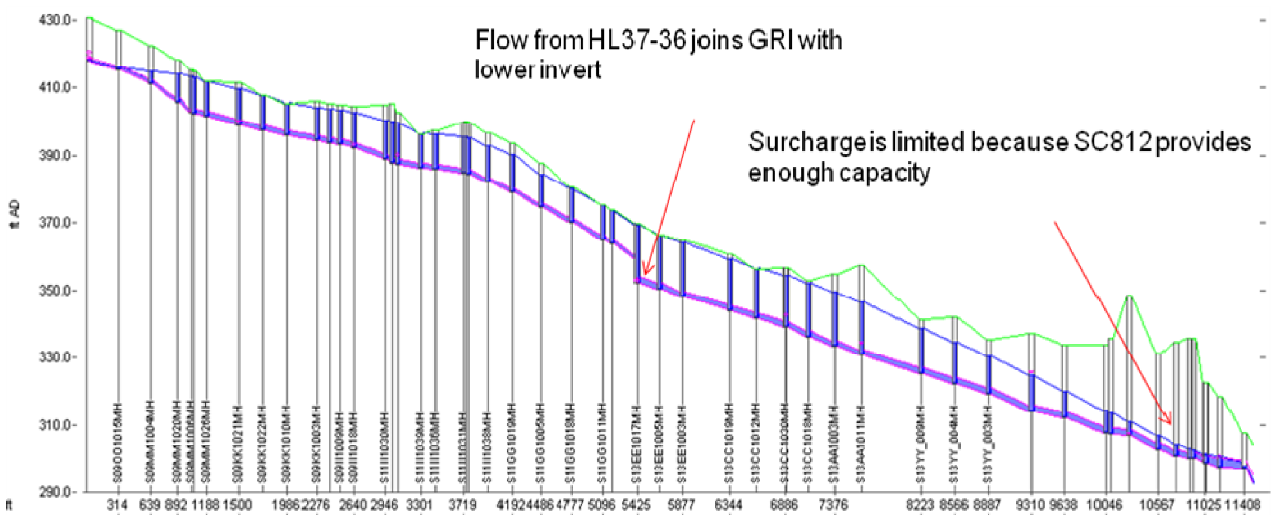


Figure 5.3.10 – Maximum Hydraulic Grade Line along Upper Gwynns Run Interceptor in 2-Year Design Storm Condition

Lower Gwynns Run Interceptor

Figure 5.3.11 shows the maximum HGL near the downstream end of GRI for the 1-year design storm condition. As mentioned in Section 3.4.3, there are three flooded manholes for the 1-year design storm near the confluence of SC812 and the existing GRI. This Figure shows that the HGL is steeper than the pipe slope for the 27" section of GRI, which implies that this 27" section has limited capacity.

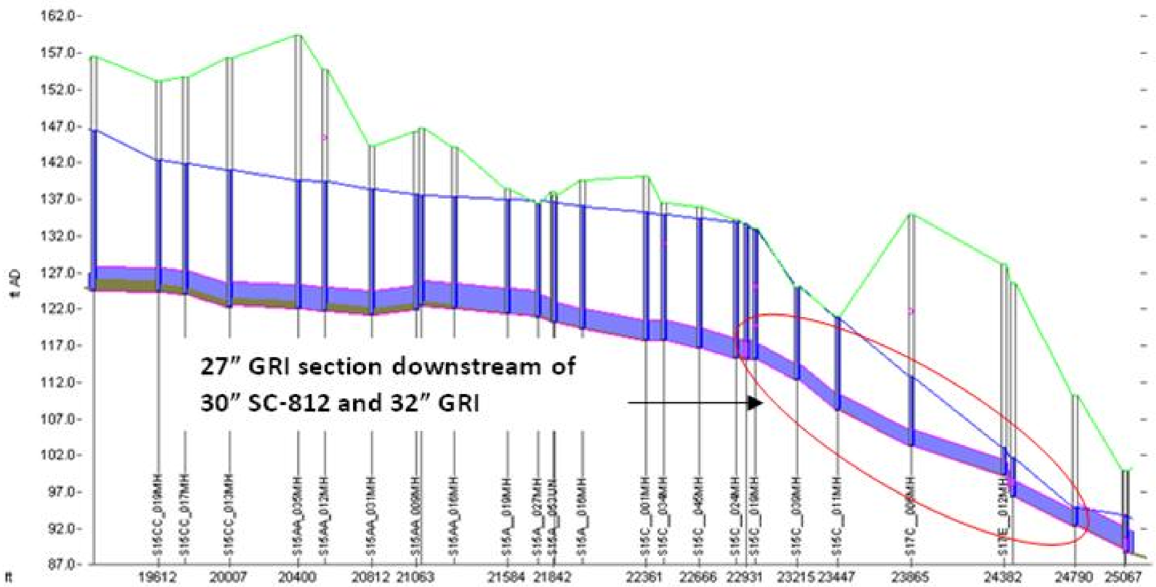


Figure 5.3.11 – Maximum Hydraulic Grade Line near the Downstream End of the Gwynns Run Interceptor in 1-Year Design Storm Condition

Eastern High Level Interceptor

Figure 5.3.12 shows the maximum HGL between the triple barrel siphon and the downstream end of HLI for the 2-year design storm condition. The four major inflows from the Jones Falls and Low Level sewersheds as well as the flow from the HLSS overwhelm the Eastern High Level Interceptor which already has a diminished capacity due to heavy sediment accumulation throughout the HLI.

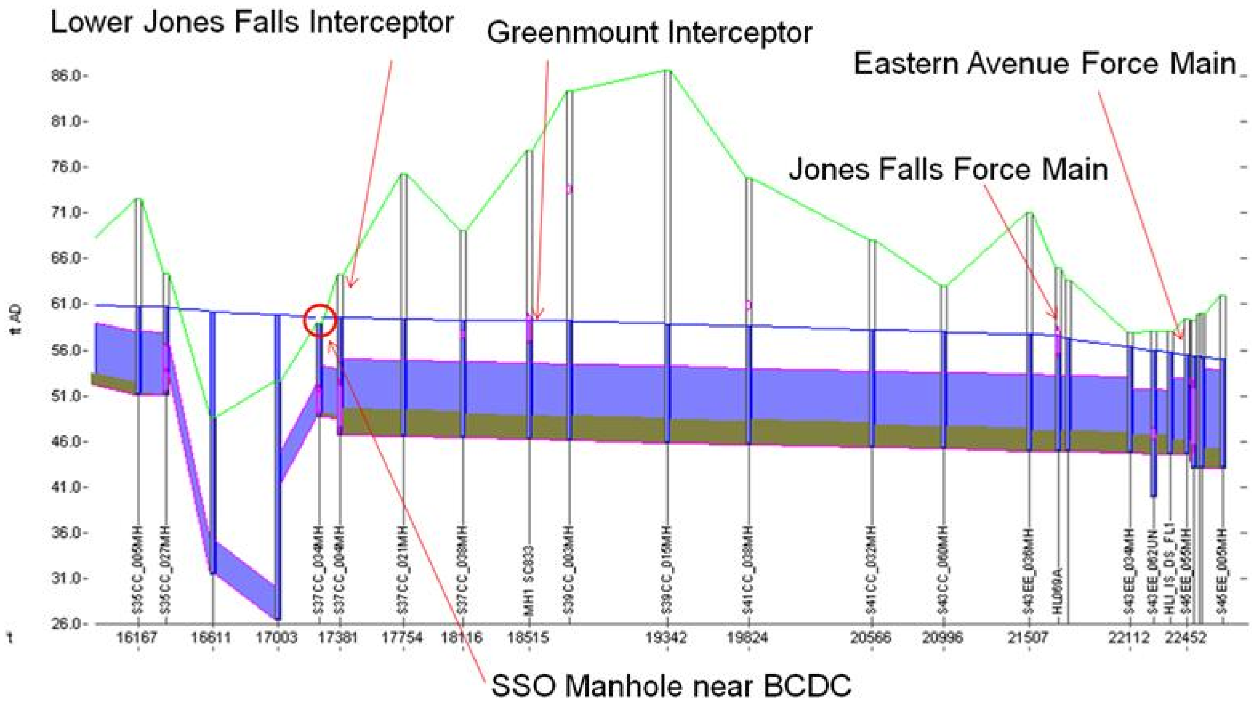


Figure 5.3.12 – Maximum Hydraulic Grade Line along High Level Interceptor between Triple-barrel Inverted Siphon and the Downstream End of the High Level Interceptor in 2-Year Design Storm Condition.

The baseline analysis and capacity assessment are further detailed in the Baltimore High Level Sewershed Baseline Analysis and Capacity Assessment Report, which is included in Attachment 5.3.1.

5.4 Alternative Analyses (2-Year and Larger Storms)

The HLSS was divided into four sub-basin study regions for alternatives analysis:

- Upper Gwynns Run Region,
- West Baltimore Region,
- High Level Siphon Region, and
- Eastern High Level Region.

The Alternative Analysis regions are defined by unique slope and boundary conditions that make these regions hydraulically independent from each other in most model runs. Hydraulic independence between regions reduces the complexity of evaluating alternatives and selecting projects. Map 5.4.1 depicts the boundaries for each of the Alternative Analysis study regions overlaid onto the BACA regions; which are not hydraulically independent.

The analysis begins by using the Future Baseline 2025 (BACA Analysis) conditions model to study projected SSO locations and volumes along with the system's hydraulic grade line (HGL) to determine locations where each of the SSO mitigation techniques, plus combinations of the three techniques, can be applied. This resulted in a revised baseline system (via a revised RDII loading, a modified physical model, or both). Simulations were run for the 2-year, 5-year, 10-year, 15-year and 20-year storm intensities in order to define alternative performance and create a new set of loadings and SSOs downstream.

The following basic recommendations were added to the model:

- Eliminate all engineered SSOs;
- Clean debris from the GRI (approximately 200 Tons for 5-year and above);
- Clean debris from the HLI (approximately 5,781 Tons for 2-year alternatives and 10,598 Tons for 5-year through 20-year alternatives);
- Retain discharge from the Ashburton Washwater Lake for 72 hours following the storm; and
- Extend the SC812 relief sewer to a point of connection with the HLI.

After the basic recommendations were added to the physical model, then various storage, relief and rehabilitation/renewal (I/I Rehabilitation) combinations were modeled under three distinct Upper Gwynns Run Region rehabilitation/renewal extents as outlined in Table 5.4.1. Each rehabilitation extent is further divided by using different combinations of SSO mitigation techniques to create a range of alternatives and corresponding code. Table 5.4.3 lists the mitigation techniques and corresponding codes.

Table 5.4.1 – UGR I/I Rehabilitation Extents	
A	No sub-basins
B	4 sub-basins
C	11 sub-basins

Table 5.4.2 – Design Storm	
2	2-Year Design Storm
5	5-Year Design Storm
10	10-Year Design Storm
15	15-Year Design Storm
20	20-Year Design Storm

Table 5.4.3 – SSO Mitigation Techniques	
S	Storage
R	Relief
I	Additional I/I Rehabilitation

Example: B.15.SR = 4 sub-basins in UGR were rehabilitated, 15-Year design storm was applied, Storage and Relief improvements were added

An Alternatives Technique Matrix was created to organize each of the modeled SSO mitigation alternatives for comparison. The matrix is comprised of individual alternatives logically arranged by storm intensity, and a detailed description of each is found in the following documents created by the HL Team for internal use:

- The Simulation Log[1] and
- Cost estimating spreadsheet.

The basic recommendation for the WB Region is the completion of the SC812 project. That recommendation establishes a ceiling for the UGR regional capacity at 18 million gallons per day (MGD). Any flow greater than 18 MGD will require capacity improvements in the WB Region. This places a premium value on UGR region alternatives that limit UGR interceptor discharge to 18 MGD. As the peak flow at the upstream end of SC812 increases, the maximum hydraulic grade line (HGL) along the GRI and HLI increases in elevation and remains elevated for longer period of time, which causes increases in the number and volumes of SSOs. To mitigate these SSOs caused by higher peak flows from the UGR region, more improvements are needed in the WB Region. To give incentives for alternatives with a lower peak flows from the UGR interceptor, a simple cost versus peak relationship was developed (see Figure 5.4.1) using several alternatives developed for the whole HLSS for different storm intensities. This analysis was done to screen UGR Region alternatives based on their influences to the WB region.

[1] A spreadsheet which documents the combination and details of the mitigation techniques is included in each modeled alternative simulation for internal use.

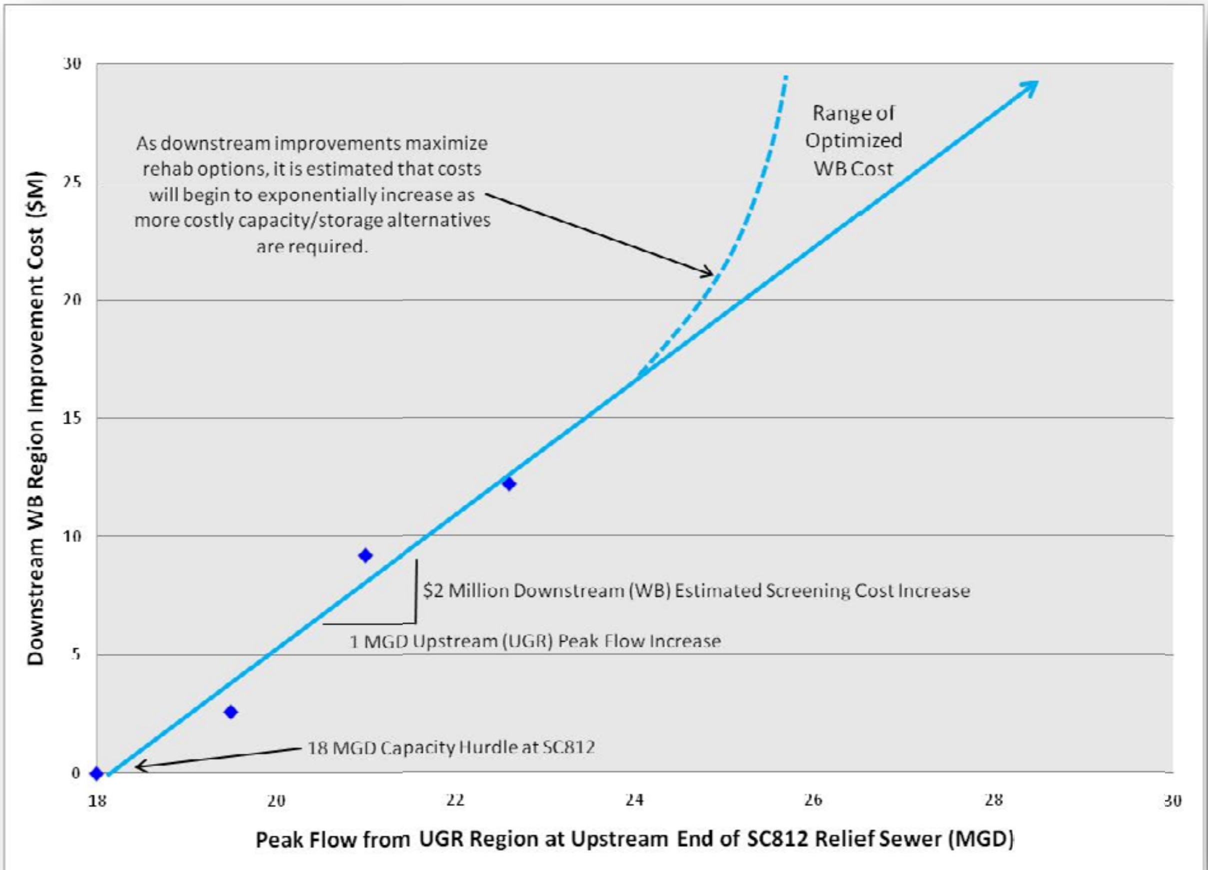


Figure 5.4.1 – Basis for West Baltimore Region Screening Cost Estimation

The HLSS team compared the improvement costs with the peak flows at the upstream end of the SC812 relief sewer for four of the selected alternatives, which had peak flows varying from 18 to 22.6 MGD. After plotting the relationship of these downstream WB improvement costs versus the contributing peak flow at the upstream end of the SC812 relief, it is clear that there is a linear relationship of $2 million per 1 MGD increment for peak flow. This relationship was extrapolated and the incremental increase in cost was applied to the all applicable alternatives developed for the UGR Region. It is important to note, however, that the incremental cost increase would likely exponentially increase as the downstream low-cost rehabilitation improvements are maximized and more costly storage and relief options would be required for the increasing peak flow contributions.

For a complete description of the proposed projects to eliminate all sanitary sewer overflows for the required design storms and a breakdown of the individual project costs, please see Attachment 5.4.1: High Level Alternatives Analysis and Recommendations Report. Maps 5.4.2 through 5.4.6 show the recommended improvements for each of the storm events.

2-YEAR IMPROVEMENTS

Upper Gwynns Run

The HLSS Team recommends alternative B2.SR to mitigate the 2-year overflows in this region. This alternative is a combination of three mitigation techniques: rehabilitation/renewal, new relief sewer and underground storage. The rehabilitation/renewal consists of inflow and infiltration reduction by CIPP lining of all non-lined sewers and manholes. The HLSS Team recommends rehabilitation/renewal for sub-basins HL37 & HL40. These sub-basins were chosen because of their high RDII values and ability to mitigate SSOs. A 2,400 LF 15-inch diameter relief sewer is needed from S11II1019MH at Ridgewood Avenue to a 60,000 ft3 (0.45 MG) underground storage tank along GRI at the City owned Towanda Park. The park is located at 4126 Towanda Avenue. The storage tank is recommended to be constructed under the park's soccer field to temporarily store the excessive RDII flow. The storage does not need to be pumped for drainage since there is a seven foot drop in the GRI sewer line near the soccer field and sufficient downward slope nearby.

In the Liberty Heights area (HL32 & HL33), 2,800 LF of 15-inch same trench relief from S09UU_007MH to S13UU_008MH is recommended by the HLSS Team. A separate study was conducted to mitigate three engineered SSOs (#132, 134, and 135) and the 15-inch same trench technique was recommended in that study. Pipe upsizing is not necessary for 2-year SSO mitigation.

West Baltimore

The HLSS Team recommends extending the recently constructed SC812 relief sewer to the High Level Interceptor to mitigate the 2-year overflows in the WB region. To complete SC812, approximately 2,400 LF of 30-inch diameter sewer pipe and approximately six manholes need to be constructed to connect to the HLI at S17I__027MH. This project will mitigate the reoccurring overflows along Franklin Street where SC812 currently ends.

Eastern High Level

Heavy Cleaning of the eastern HLI is recommended by the HLSS Team to mitigate the 2-year storm event SSOs in the EHL Region. Approximately 5,780 Tons of debris is estimated to be removed between S37CC_034MH and S45EE_005MH. This section of HLI ranges in size from 100-inches in diameter to 144-inches wide by 129-inches high.

5-YEAR IMPROVEMENTS

Upper Gwynns Run

The HLSS Team recommends alternative B5.SRI to mitigate the 5-year overflows in the UGR region. This alternative is a combination of the three mitigation techniques: rehabilitation/renewal, new relief sewer and underground storage. The rehabilitation/renewal consists of inflow and infiltration reduction by CIPP lining of all non-lined sewers and manholes. This is recommended for sub-basins HL32, 33, 38, 39 and 41 in addition to the sub-basins already recommended for 2-year rehabilitation/renewal, which are HL37 & 40. These sub-basins were chosen because of their high RDII values and ability to mitigate SSOs.

Rather than using the long 15-inch relief sewer recommended for the 2-year improvements, 500 LF of 72-inch in-line storage is proposed from S11II1019MH to S11II1038MH near the Ridgewood Avenue residential neighborhood. The combination of the additional rehabilitation/renewal in sub-basins HL38, 39 & 41 and the 72-inch in-line storage cost less than using the long 15-inch relief for the 5-year analysis. In addition, a 100,000 ft^3 (0.74 MG) underground storage tank is needed along GRI at the City-owned Towanda Park. The in-line storage at Ridgewood Avenue can reduce the peak flow significantly along the GRI. The B5.SR alternative, which uses the 15-inch relief requires an 180,000 ft^3 (1.3 MG) storage tank due to the higher peak flow. The proposed in-line storage helps minimize the tank size at the Towanda Park soccer field.

The profile view of the 72-inch underground in-line storage/relief technique used for the 5-, 10-, and 15-year recommendations is shown below in Figure 5.4.2. The 72-inch storage pipeline has an elevated inlet so that the storage is used for wet weather surcharged conditions. The outlet of the proposed in-line storage is 8-inch in diameter to maximize the in-line storage volume and limit the discharge from the storage. This mitigation technique was only used in the heavily populated residential area around Ridgewood Avenue where an acceptable location for a storage tank could not be found.

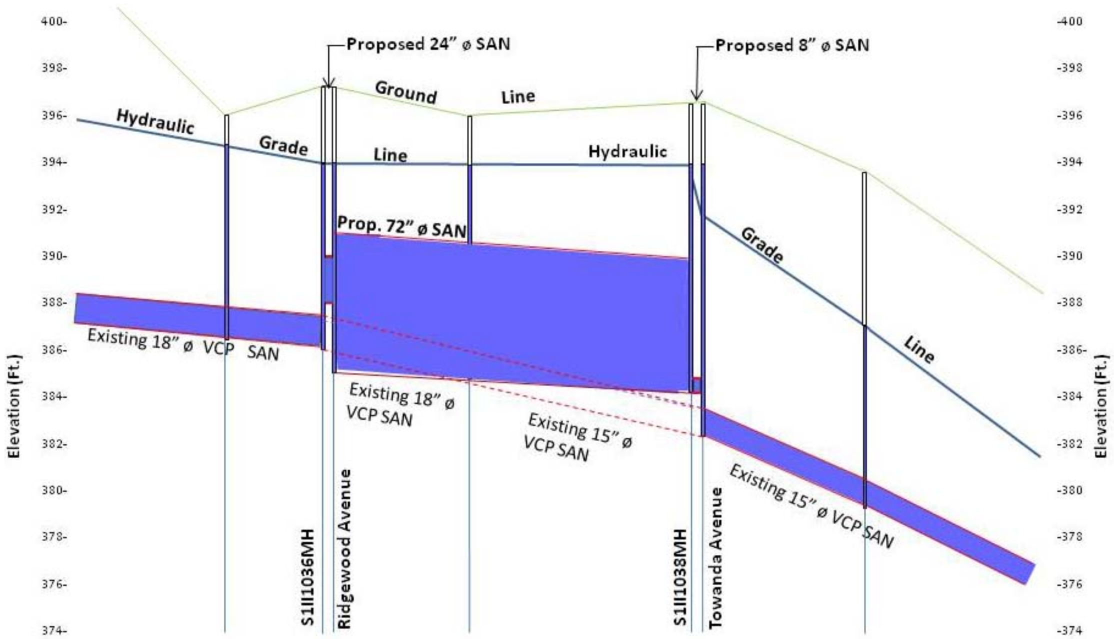


Figure 5.4.2 –In-line Storage/Relief Technique for Ridgewood Ave. Neighborhood

In the Liberty Heights area (HL32 & HL33), 2,800 LF of 15-inch same trench relief from S09UU_007MH to S13UU_008MH is recommended by the HLSS Team. No pipe upsizing is needed for the 5-year improvements.

West Baltimore

In addition to the 2-year improvements in the WB region, the HLSS Team recommends rehabilitation/renewal in the form of CIPP lining for sub-basin HL23 to mitigate the 5-year storm event overflows in this region. HL23 is a small sub-basin (92 acres), but the median R capture coefficient is very high (11.2%) and RDII has a fast inflow pattern rather than a slow infiltration pattern. Therefore, HL23 would be a good location for a comprehensive rehabilitation/renewal program.

The HLSS Team recommends heavy cleaning in the WB region to remove approximately 200 Tons of debris from the GRI and 4,820 Tons of debris from the HLI. This cleaning will increase interceptor capacity in this region and mitigate SSOs.

Eastern High Level

Heavy cleaning of the eastern HLI is also recommended by the HLSS Team to mitigate the 5-year storm event SSOs in the EHL Region. Approximately 5,780 Tons of debris is estimated to be removed between S37CC_034MH and S45EE_005MH.

10-YEAR IMPROVEMENTS

Upper Gwynns Run

The HLSS Team recommends alternative B10.SRI to mitigate the 10-year overflows in the UGR region. This alternative is a combination of the three mitigation techniques: rehabilitation/renewal, new relief sewer and underground storage. The 10-year recommendation is built on the 5-year recommendation. The HLSS Team recommends no additional CIPP lining to the seven UGR Regions recommended for the 5-year (HL32, 33, 37, 38, 39, 40 and HL41). A 1,500 LF 15-inch UGRI relief pipeline is necessary to connect the upstream (Ridgewood Avenue) and downstream (Towanda Park) storage locations. Volume of the downstream Towanda Park storage needs to be increased to 120,000 ft3 (0.90 MG). This is about 0.16 MG larger than the storage required for a 5-year storm.

Instead of using the combination of upstream 72-inch underground in-line storage and 15-inch UGRI relief, a 21-inch 2,400 LF UGRI relief sewer can be used (Alternative B10.SR). However, the downstream Towanda Park storage volume needs to be 2.2 MG to handle the higher peak flow being conveyed by the larger relief sewer. The estimated cost of this combination of techniques becomes higher than the recommended alternative.

To mitigate the 10-year overflows in the Liberty Heights area (HL32 & HL33) the HLSS Team recommends using 550 LF of 18-inch diameter relief sewer from S09UU_001MH to S11UU_016MH. The upsize is due to the flat terrain of this area. The remainder of the 2,800 LF relief sewer is 15-inch in diameter.

West Baltimore

The HLSS Team recommends a combination of rehabilitation/renewal and sewer upsizing in addition to the 5-year WB recommendations to mitigate the 10-year overflows in this region. The Team selected sub-basins HL24 and HL27 in addition to HL23 for rehabilitation/renewal since these two sub-basins have relatively higher capture coefficients (6.0% for HL24 and 8.7% for HL27). Also, 900 LF of sewer upsizing from 37-inches to 42-inches is required to handle high flows from the sub-basins HL20-41 and TSHL03.

The HLSS Team also recommends heavy cleaning in the WB region to remove approximately 200 Tons of debris from the GRI and 4,820 Tons of debris from the HLI. This cleaning will increase interceptor capacity in this region and mitigate 10-year storm event SSOs.

Eastern High Level

Heavy cleaning of the eastern HLI is also recommended by the HLSS Team to mitigate the 10-year storm event SSOs in the EHL Region. Approximately 5,780 Tons of debris is estimated to be removed between S37CC_034MH and S45EE_005MH.

15-YEAR IMPROVEMENTS

Upper Gwynns Run

The HLSS Team recommends alternative B15.SRI to mitigate the 15-year overflows in the UGR region. This alternative is a combination of the three mitigation techniques: rehabilitation/renewal, new relief sewer and underground storage. The 15-year recommendation is built on the 10-year recommendation. In addition to the 10-year recommendation, rehabilitation/renewal is needed for HL36 also, and sewer upsizing of approximately 1650 LF is needed from 8-inch to 10-inch or 10-inch to 12-inch. The downstream underground storage at Towanda Park should be increased to 150,000 ft3 (1.1 MG), which is about 0.22 MG larger than the storage required for the 10-year storm.

To mitigate the 15-year storm event overflows in the Liberty Heights area (HL32 & HL33) the HLSS Team recommends constructing a 550 LF of 18-inch diameter relief sewer from S09UU_001MH to S11UU_016MH. The remainder of the 2,800 LF relief sewer is 15-inch in diameter.

West Baltimore

The HLSS Team recommends rehabilitation/renewal in addition to the 10-year recommendation of sub-basin HL28 to mitigate the 15-year storm event overflows in this region. HL28 was selected because it is a large sub-basin (235 acre) and has a relatively high median R capture coefficient (8%).

The HLSS Team also recommends heavy cleaning in the WB region to remove approximately 200 Tons of debris from the GRI and 4,820 Tons of debris from the HLI. This cleaning will increase interceptor capacity in this region and mitigate 15-year storm event SSOs. Pipe upsizing from 37-inches to 42-inches is also needed for 773 LF in this region.

High Level Siphon

After conducting hydraulic analysis of the HL siphon the HLSS Team has determined that under storm intensities greater than 10-year frequency, cleaning of the siphon will be required to alleviate SSOs upstream of the siphon. For details regarding the siphon analysis see Section 4.0 of the HL Alternatives Analysis and Recommendations Report, Attachment 5.4.1. Therefore, cleaning of the two 42-inch barrels of the HLI inverted siphon is recommended by the HLSS Team for the 15-year storm event.

Eastern High Level

Heavy cleaning of the eastern HLI is also recommended by the HLSS Team to mitigate the 15-year storm event SSOs in the EHL Region. Approximately 5,780 Tons of debris is estimated to be removed between S37CC_034MH and S45EE_005MH.

20-YEAR IMPROVEMENTS

Upper Gwynns Run

The HLSS Team recommends alternative C20.SR to mitigate the 20-year overflows in the UGR region. This alternative is a combination of the three mitigation techniques: rehabilitation/renewal, new relief sewer and underground storage. The 20-year recommendation is not built on the 15-year recommendation since the benefit of using the upstream storage decreases. Rehabilitation/Renewal is recommended by the HLSS Team for all sub-basins in the UGR Region, e.g. CIPP lining sub-basins HL31-41. The whole region rehabilitation/renewal decreases the maximum HGL along the GRI and helps to minimize the storage volume needed at Towanda Park to 130,000 ft3 (0.97 MG). Sewer upsizing of about 3,100 LF is needed from 8-inch to 10-inch or 10-inch to 12-inch.

To mitigate the 20-year overflows in the Liberty Heights area (HL32 & HL33) the HLSS Team recommends constructing a 550 LF 18-inch diameter relief sewer from S09UU_001MH to S11UU_016MH. The remainder of the 2,800 LF relief sewer is recommended to be 15 inches in diameter.

West Baltimore

To address the 20-year overflows, minimal additional improvements are needed for the WB region, on top of the improvements recommended for the 15-year storm. The reason is that more rehabilitation/renewal is recommended in UGR for the 20-year storm. Eleven sub-basins in the UGR region (HL31 to HL41) are recommended for the 20 year and only 8 sub-basins are rehabilitated in the 15-year improvements (HL31-41 except HL31, 34 and 35). The three additional rehabilitation/renewal sub-basins for the UGR region decreases the peak at the upstream end of SC812 and eliminates the need for additional 20-year storm event improvements other than 352 LF of pipe upsizing from 8-inches to 10-inches.

High Level Siphon

Cleaning of the two 42-inch barrels of the HLI inverted siphon is also recommended by the HLSS Team for the 20-year storm event.

Eastern High Level

Heavy cleaning of the eastern HLI is also recommended by the HLSS Team to mitigate the 15-year storm event SSOs in the EHL Region. Approximately 5,780 Tons of debris is estimated to be removed between S37CC_034MH and S45EE_005MH.

The total estimated recommended improvement costs for the entire HLSS based per design storm return period are presented in Table 5.4.3. The estimated improvement cost per gallon of SSO removed is shown in Table 5.4.4.

The City has calculated that the current cost to transport and treat wastewater from the High Level Sewershed to the Back River Wastewater Treatment Plant is $1.49 per 1,000 gallons. Using this number, the City is estimated to save money in treatment and conveyance costs. Table 5.4.5 shows the estimated convey and treat savings per storm event. Additional savings are also likely given that an effective I&I reduction program could mitigate the need for costly peak flow expansion at the wastewater treatment plant.

Table 5.4.4 – Total Estimated Improvement Cost for High Level Sewershed

Table 5.4.4: Total Estimated Improvement Cost for High Level Sewershed (in millions of dollars)									
		5-year		10-year		15-year		20-year	
Projected Year	2-year	Add.	Cum.	Add.	Cum.	Add.	Cum.	Add.	Cum.
2008	$21.06	$16.07	$37.13	$12.66	$49.79	$11.58	$61.37	$6.67	$68.04
2009	$22.54	$17.19	$39.73	$13.54	$53.27	$12.40	$65.67	$7.13	$72.80
2010	$24.11	$18.40	$42.51	$14.49	$57.00	$13.27	$70.27	$7.63	$77.90
2011	$25.80	$19.69	$45.49	$15.50	$60.99	$14.19	$75.18	$8.17	$83.35
2012	$27.61	$21.06	$48.67	$16.59	$65.26	$15.19	$80.45	$8.73	$89.18
2013	$29.54	$22.54	$52.08	$17.75	$69.83	$16.25	$86.08	$9.35	$95.43
2014	$31.61	$24.12	$55.73	$18.99	$74.72	$17.38	$92.10	$10.01	$102.11
2015	$33.82	$25.81	$59.63	$20.32	$79.95	$18.60	$98.55	$10.70	$109.25
2016	$36.19	$27.61	$63.80	$21.74	$85.54	$19.91	$105.45	$11.45	$116.90
2017	$38.72	$29.55	$68.27	$23.26	$91.53	$21.30	$112.83	$12.26	$125.09

Table 5.4.5 – Estimated Improvement Costs per Gallon SSO Removed

Table 5.4.5: Estimated Improvement Costs Per Gallon SSO Removed					
Million Gallons Removed	2-year	5-year	10-year	15-year	20-year
	6.14	10.55	14.65	17.14	19.18
2008	$3.43	$3.52	$3.40	$3.58	$3.55
2009	$3.67	$3.77	$3.64	$3.83	$3.80
2010	$3.93	$4.03	$3.89	$4.10	$4.06
2011	$4.20	$4.31	$4.16	$4.39	$4.35
2012	$4.50	$4.61	$4.45	$4.69	$4.65
2013	$4.81	$4.94	$4.77	$5.02	$4.98
2014	$5.15	$5.28	$5.10	$5.37	$5.32
2015	$5.51	$5.65	$5.46	$5.75	$5.70
2016	$5.89	$6.05	$5.84	$6.15	$6.10
2017	$6.31	$6.47	$6.25	$6.58	$6.52

Table 5.4.6 – Total Estimated HLSS Conveyance & Treatment Savings per Storm

Table 5.4.6: Total Estimated HLSS Conveyance & Treatment Savings Per Storm					
Design Storm	Baseline Condition Total Volume at Outfall	Recommended Alternative	Alternative Total Volume at Outfall	Volume Reduced By Recommended Alternatives	Convey & Treat Savings per Storm
Year	MG	Year	MG	MG	Dollars ($)
2	284.940	B2.SR	282.745	2.195	$3,271
5	301.048	B5.SRI	294.132	6.916	$10,305
10	313.835	B10.SRI	304.267	9.568	$14,256
15	320.619	B15.SRI	308.604	12.015	$17,902
20	326.904	C20.SR	312.950	13.954	$20,791

6.0 GEOGRAPHIC INFORMATION SYSTEM (GIS)

6.1 Overview of GIS

The City of Baltimore maintains a robust Geographic Information System (GIS) representing the wastewater infrastructure. The GIS is housed in an ESRI format Geodatabase and leverages the enterprise capabilities of ArcSDE. An integral part of the sewershed study is the update of the GIS to represent the existing conditions at the time of the study. These updates provided to the City were considered “Core” data deliveries as they are the primary or core repository of data representing the wastewater infrastructure. This is in comparison to “non-core” data which was the supplemental data provided to the City such as manhole inspection reports, CCTV video, etc.

This section describes the City’s GIS system; describes the methods and procedures used during the project to update the system; and the quality assurance procedures performed to verify the accuracy of the work performed.

The wastewater utility geodatabase is comprised of three thematic groups of features:

- Lines Thematic Group – contains wastewater features that can be represented as lines whose direction indicates the direction of flow. These line features make up the foundation of the wastewater network. All features in this thematic group participate in the geometric network. These features include:

    - House Connection (line)
    - Sewer (line)

- Features Thematic Group – contains wastewater features that can be represented as points, lines and/or polygons. The features in this thematic group do not affect flow and will not participate in the geometric network. Traces and other network analysis operations do not consider these entities, yet they are captured in the database to provide a more complete representation of the system. These features include:

    - Casing (polygon)
    - Facility (polygon)
    - Lamphole (point)
    - Manhole Cover (point)
    - Structure (polygon)

- Devices Thematic Group – contains wastewater features that can be represented as points. All features in this thematic group participate in the geometric network. These features include:

    - Manhole Junction (point)
    - Meter Station (point)

- Pump Station (point)
- Treatment Plant (point)
- Bend (point)
- Valve (point)
- House End (point)
- House Intersection (point)
- House Sewer Intersection (point)
- Sewer End (point)
- Sewer Intersection (point)

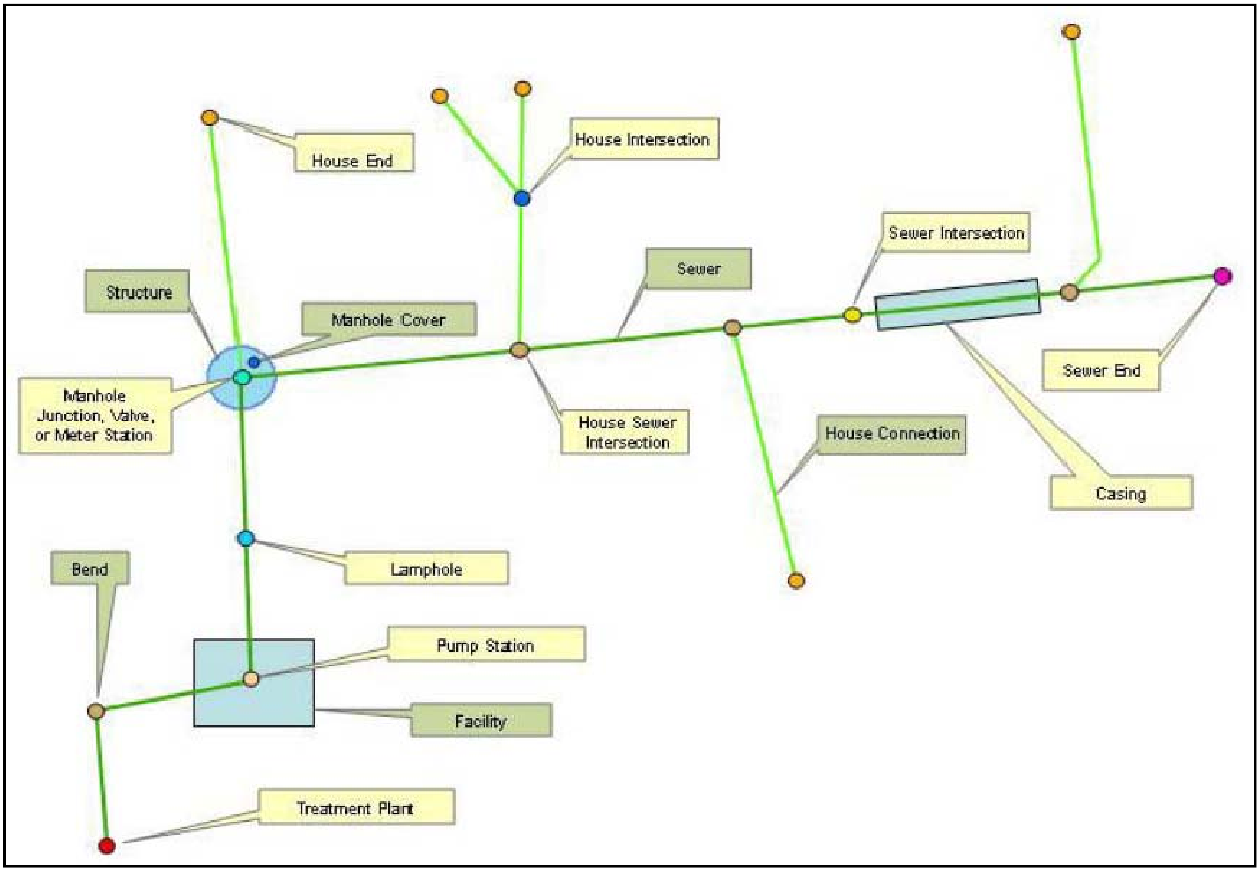


Figure 6.1.1 – Feature Objects in City's Wastewater GIS

6.2 Field Data and GIS Integration

The Sewershed Study and Evaluation project involved extensive field activities which generated significant amounts of non-core data to be used to update the core GIS. Specifically, the non-core data generated was:

- Manhole Inspection Data
- GPS Survey Data
- Closed Circuit Television (CCTV) Inspection Data
- Smoke Testing
- Dyed Water Testing Data

The majority of the spatial and attribute edits made to the wastewater geodatabase were based on information extracted from these non-core datasets. When current conditions could not be established through these sources, additional engineering contract document research was performed to populate the GIS. The following is further description regarding the field collected data and its use in updating the GIS.

Manhole Inspections
Manhole inspections were performed on 4575 manholes in the High Level Sewershed. Information was collected using a custom designed Manhole Inspection Application Software (MIAS) application. MIAS allows field crews to collect detailed attribute information about the physical characteristics of a manhole, its sewer connections, and the manhole's surrounding environment. In addition to characteristics such as size, shape, and material, the application records the condition and infiltration properties of the manhole's features. The MIAS application captures inventory and condition information for the following manhole components:

- Location
- Environment
- Cover
- Frame
- Chimney/Stack
- Corbel
- Barrel
- Bench
- Channel
- Pipe Connections

The unique identifier used in both the GIS and MIAS datasets is the MANHOLE_ID field. This common field allowed for database joins which facilitated integration of the manhole inspection field information directly into wastewater feature attribute fields.

In addition to data collected in the MIAS application, inspectors also recorded changes between actual field conditions and the current GIS information on paper plots of the GIS data. This provided a convenient medium to record additional remarks that were then later modified in the GIS by technicians.

Roughly 33468 manhole inspection photos were taken during the manhole inspections in the High Level Sewershed. The MIAS application and other GIS tools provided easy access to these photos for use in checking and validating the manhole information being entered into the database.

GPS Manhole Surveys

The High Level Sewershed team chose to use survey-grade GPS devices to locate modeled and non-modeled manholes. Non-modeled manholes were first attempted to be located using City provided Orthophotography with a known accuracy of one (1) foot plus or minus as measured on the earth's surface. A total of approximately 3631 survey-grade GPS survey locations of manhole covers were completed during the project. The horizontal locations captured by both the survey-grade GPS and orthophoto placement allowed us to meet the project's 5 foot accuracy requirement for non-modeled manholes and the 2 foot requirement for modeled manholes

These GPS locations were used to position key manhole features and to establish the rim elevation stored in the manhole junction GIS feature class. The GPS rim elevations were used along with depths measured during the manhole inspection to establish pipe invert elevations in the sewer feature layer.

Rim elevations for manholes that were not GPS surveyed were extracted from a -Digital Elevation Model (DEM) layer developed using City supplied spot elevation and contour data. The ground to rim height, measured in the manhole inspection was added (or subtracted) from the -DEM elevation to determine the rim elevation before calculating pipe invert elevations.

CCTV Inspections

The High Level sewershed study plan team completed and delivered approximately 5700 individual CCTV sewer inspections. The up and down nodes for each CCTV survey were verified that they link to a valid GIS manhole, or sewer end features that represent the starting and ending locations of the survey.

With the data relationship established, the CCTV surveys, manhole inspections (MIAS database) and the GIS were compared to assist in GIS attribute updating.
The CCTV surveys were invaluable in the GIS updating process by enabling Engineers and GIS technicians to:

- Locate previously unknown buried manholes and to incorporate them into the GIS at their proper location.

- Establish the existence of manholes in the GIS
- Validate sewer length against the GIS
- Identify the proper location of changes or fixtures in the system:
    - Size changes
    - Material changes
    - Angular changes
    - Tees and Wyes (sewer mains connecting without a manhole)

Smoke and dyed water testing

Smoke and dyed water testing were performed in areas where the cross-connections with storm drains were suspected and continuity of the pipe network could not be determined through other methods. Reports including photo documentation were prepared and were then used by technicians to appropriately modify the GIS data. In total, 283 smoke testing reports were generated and 12 dyed water testing reports were generated for the High Level Sewershed.

6.3 Office Research and GIS Updates

The compilation of field collected data allowed GIS technicians to update a significant amount of the GIS representation of the wastewater infrastructure. Prioritization of the applicability of the variety of sources was performed on an attribute by attribute basis based upon the guidance provided by the City's Baltimore Sewer Evaluation Standards manual (BaSES). Some features or attributes could not be adequately quantified using the collected field information and required additional research of Baltimore's record plat maps and engineering contract drawings.

Using standard ESRI editing functionality in the ArcGIS platform as well as custom tools for GIS updates, GIS technicians utilized the sources available to them to update the wastewater geodatabase. As tiles in the City's standard grid index were completed and quality assurance approved, the data was synchronized back to the City for quality control review by the data clearinghouse.

6.4 QA/QC Review and Procedures

A variety of procedures were performed for quality assurance and quality control of the wastewater geodatabase.

- Oversight and manual spot checks by engineers were performed for quality assurance.
- ArcInfo topology checks to verify feature topology; feature snapping; flow tracing; and location of duplicate features.
- Database queries to compare the GIS datasets with the other non-core data sources were executed to review for anomalies.

- An automated suite of 171 quality control tests built in the ESRI Production Line Tool Set (PLTS) platform were run against the dataset both by the sewershed consultant as well as the data clearinghouse. These tests perform a variety of checks on features and feature attributes, including: domain validation, attribute, logical, spatial, and topologic.

6.5 GIS Certification

The High Level Sewershed team has followed the processes described above and those described in more detail in the City BaSES manual to update the City of Baltimore's wastewater GIS for the High Level Sewershed. The City of Baltimore and the High Level Sewershed team are hereby certifying that the GIS data represented in the High Level Sewershed portion of the City's GIS provides the necessary data for the adherence of Paragraph 14 Information Management System Program.

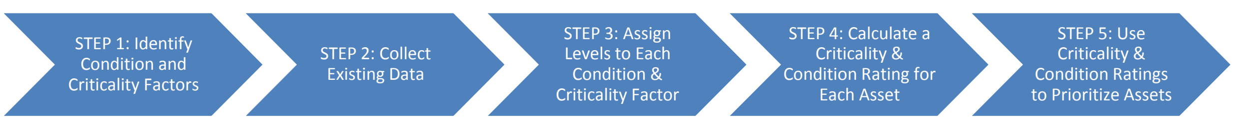
The High Level Sewershed portion of the City's GIS is the best assessment of current conditions achievable with the available technology and source data. Current conditions are defined as of 08/31/2008. Furthermore, the City of Baltimore has instituted processes to ensure that should changes to the sewer infrastructure in the High Level Sewershed occur; the GIS will be updated within 90 days of the changes.

7.0 RECOMMENDATIONS

As required by the Consent Decree (CD), each Sewershed Study and Plan is required to identify specific improvements or other corrective actions needed to address deficiencies identified during the sewershed evaluation to aid in reducing rainfall dependent inflow and infiltration (RDI/I) contributing to sanitary sewer overflows (SSO's) or engineered overflows; address deficiencies identified during the hydraulic analyses and address other deficiencies that contribute to SSO's in the High Level Sewershed. This section outlines how the data analysis, evaluation and the decision-making criteria were utilized to identify and prioritize improvements within the High Level Sewershed.

7.1 Decision Making Criteria

As part of the sewershed studies, the City developed a condition and criticality protocol that provides a framework for a continuous rehabilitation strategy of all collection system components based on both criticality (consequence of failure) and condition (probability of failure). Assets whose failure can have large impacts on the community and the environment and whose condition is the poorest will receive a higher criticality rating and will receive attention sooner. Assets that receive a lower criticality rating will receive some level of continued monitoring but no immediate action or rehabilitation at this time. The prioritization process consists of five steps illustrated below.



Step 1 - Identify the condition and criticality factors that will be used to assess the sewer system. These factors have been identified and include proximity to human population, to bodies of water, to forests, and to wildlife habitat that could potentially be affected by a sewer system failure.

Step 2 - Collect data that will be used to evaluate each factor including CCTV inspection data, manhole inspection data, GIS data, results of hydraulic modeling, and sewer complaint data.

Step 3 - Assign different levels to each factor so that sewer assets can be differentiated in terms of their condition or criticality.

Step 4 -Assign a condition and criticality rating for each sewer asset. The ratings are assigned by using the level assigned to each factor and the relative importance of each factor.

Step 5 -Use the ratings to prioritize the system and determine short-term and long-term rehabilitation projects.

For each category, factors will be used to measure the criticality and condition of every asset. Table 7.1.1 below lists the condition and criticality categories and factors that were considered.

Table 7.1.1 – Condition and Criticality Factors

Criticality Category	Criticality Factor
Quantity of Flow Conveyed	Pipe Diameter
Transportation/Urban Impact	Proximity to Historic Areas Proximity to Community Areas (Parks, Schools, Etc.) Traffic Conditions Proximity to Railroad Easements
Environmental Impact	Proximity to Forested Areas Proximity to Waterways / Streams Proximity to Wetlands
Public Health Impact	Population Density Proximity to Floodplains
Ease of Emergency Repair	Accessibility Ability to Re-route Flow Proximity to City Conduits Building Encroachment System Redundancy Emergency Power Ability to Bypass Flow Pipe Depth
Condition Category	**Condition Factor**
Structural Condition	Structural Pipe Rating Manhole Inspection Rating
Maintenance Frequency	O&M Pipe Rating Number of SSOs or CSOs Known Maintenance Issues Documented RDI/I Rates
Capacity	Need for Additional Capacity

Each condition and criticality factor is assigned a rating from 1 to 5. The purpose of assigning ratings to each condition and criticality factor is to differentiate sewer pipes and manholes in terms of the consequences and probability of their failure.

The rating assigned increases as the consequence of failure or probability of failure increases. For example, a break in a 24-inch diameter interceptor sewer can result in more wastewater being released than a break in an 8-inch diameter collector sewer. Therefore, the larger diameter pipe has a higher criticality rating based on the amount of flow being conveyed. The 24-inch diameter interceptor sewer would be assigned a higher rating (5) for the 'Quantity of Flow Conveyed' criticality factor and the 8-inch diameter collector sewer would be assigned a lower rating (1) for the same factor.

After a rating of 1 through 5 is assigned, an overall criticality rating and an overall condition rating is calculated for each system component. The criticality rating is calculated using the highest individual level assigned to any of the criticality factors multiplied by a relative importance value. The relative importance value for the criticality rating is the weighting, expressed as a percentage, applied to each criticality factor to calculate an overall rating. The relative importance values are the same for each collection system component and are presented in Table 7.1.2.

Table 7.1.2 – Criticality Factor Relative Importance Values

Criticality Factors	Relative Importance Value
Quantity of Flow Conveyed	30%
Transportation/Urban Impact	15%
Environmental Impact	20%
Public Health Impact	15%
Ease of Emergency Repair	20%
Total:	**100%**

The final assessment culminates in a rating of 1 through 5 for criticality and utilizing NASSCO's Pipeline Assessment Certification Program (PACP) and Manhole assessment Certification Program (MACP) , a 1 through 5 rating for condition, which determines priorities for repairs or continuous condition assessment or monitoring. This approach allows the City to focus their available resources and funding on the most immediate system repair needs. Figure 7.1.1 is a matrix showing the recommended course of action for each sewer system component based on the combination of condition and criticality ratings. The vertical 1 through 5 rating scale is for condition and the horizontal 1 through 5 rating scale is a rating for an asset's criticality within the collection system.

The condition rating is equal to the highest individual level assigned to any of the condition factors (structural condition, maintenance condition, SSO, maintenance problems, capacity and r-value).

Figure 7.1.3 – Condition/Criticality Ratings Matrix

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="5">Criticality</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><th rowspan="5">Condition</th><th>5</th><td colspan="5">First Priority Rehab Program</td></tr>
<tr><th>4</th><td colspan="3">Second Priority Rehab Program</td><td colspan="2"></td></tr>
<tr><th>3</th><td colspan="5">Frequent Assessment</td></tr>
<tr><th>2</th><td colspan="3" rowspan="2">Low Priority</td><td colspan="2" rowspan="2">Regular Monitoring</td></tr>
<tr><th>1</th></tr>
</table>

Each of the recommended courses of action is briefly described in more detail below. The specific improvement projects and/or other corrective actions will vary based on the type of collection system asset (gravity sewer or manhole).

<u>First Priority Rehabilitation Program</u>

Assets that receive a condition rating of 5 regardless of criticality, and assets that receive a condition rating of 4 and criticality rating of 4 and 5 are placed at the highest priority for rehabilitation, repair or replacement. These assets lack hydraulic capacity, contribute to system inflow and infiltration (I/I) and/or are likely to fail in the near future (within the next 5 years). They present the potential for SSO's or could create a major disruption in service and potentially impact the environment and/or public health if not addressed.

<u>Second Priority Rehabilitation Program</u>

Assets that receive a condition rating of 4 and criticality rating of 1, 2, or 3 will be given second priority in the rehabilitation program. These assets contribute to system I/I, and are likely to continue to deteriorate or probably fail in 5-10 years and require attention in the foreseeable future.

<u>Frequent Assessment</u>

These assets are in fair physical condition and should have their condition assessed every 2 to 3 years, regardless of the criticality rating. The purpose of frequent assessment is to check if the condition has deteriorated to a point that the asset would need to be moved to a higher priority.

<u>Regular Monitoring</u>

These assets are typically in serviceable condition but are considered highly critical. These assets should be checked every 3 to 5 years.

<u>Low Priority</u>

These assets are believed to be in good condition and have a lower criticality rating. The assets in this category will receive some level of inspection (once every 5 to 10 years) to verify that their condition is not deteriorating.

7.2 Proposed Improvements

It should be noted that the interrelationship between the City's sewersheds, known as boundary conditions, must be understood and carefully considered before significant hydraulic repairs are completed. The Jones Falls, Herring Run, High Level, Low Level, and Dundalk sewersheds flow into the Outfall sewershed. These six sewersheds are connected and hydraulically interdependent, creating "boundary" conditions that must be defined and considered for hydraulic modeling. Ultimately, the collection system within the six interdependent sewersheds should be modeled as one. The City is developing a model to accomplish the system-wide modeling, which will be refined and improved as the individual sewershed studies complete calibration of their respective sewershed models. This Plan provides certain recommended improvements that would be implemented by the City in accordance with a proposed schedule. However, the Plan should not be considered final and may require amendment as necessary once the system-wide hydraulic model is completed and system-wide simulations are performed. **System-wide simulations to be conducted by the City in the near future could alter the recommendations identified herein.**

Once the sewer system improvement projects and/or other corrective actions required to address deficiencies were identified and ranked based on the criticality and condition ratings; assets that received a condition rating of 5, regardless of criticality, were included in a "First Priority" corrective action plan. Assets that had a condition rating of 4 and a criticality rating of 4 or 5 were also included in a "First Priority" corrective action plan. Assets that received a condition rating of 4, but were not considered to be as critical (3 or less) were included in the "Second Priority" corrective action plan.

Asset prioritization was developed with consideration that all proposed improvement projects required to eliminate SSO's must be completed before January 1, 2016 as stipulated by the CD. These assets included First and Second Priority manholes and sanitary sewers, identified SSO structures, and recommended hydraulic improvements to the collection system. These proposed improvement projects are described in the following paragraphs.

7.2.1 Sanitary Sewer Overflow Structure Identification and Elimination

As a requirement of the City's CD, the High Level Sewershed Study (HLSS) and Plan is required to identify undocumented SSO structures. Investigations completed in support of this report have identified four (4) undocumented SSO structures in the northern reaches of the High Level Sewershed and two (2) undocumented cross-connections in HL 30 and HL 24.

Table 7.2.1 Discovered SSO Structures

SSO #	Location	Basin	Manhole ID	Storm Return Period Causing Engineered Overflow to Become Active (Modeled)
138	West Cold Spring Lane and Ayrdale Ave.	HL 37	S07EE1023MH	1-Year, 24-Hour Storm
139	W. Garrison Ave. and Queensberry Ave.	HL 40	S11QQ1002MH	5-Year, 24-Hour Storm
140	Ayrdale Ave. and Boarman-Alley-Belle	HL 37	S07EE1019MH	5-Year, 24-Hour Storm
141	Presbury and Dukeland Streets	HL 36	S13GG_042MH	1-Year, 24-hour storm
NA*	Alto-Piedmont Alley	HL 30	S09OO_049MH	Not designed to relieve sanitary system.
NA*	In alley behind 1844 W. North Avenue	HL 24	S21KK_010MH	20-Year, 24-Hour Storm

*Confirmed cross-connections which were not intended as an official SSO structure.

Metering began at the above W. Garrison Avenue and West Cold Spring Lane overflow structures in April, 2009, after their discovery, with the intent to monitor flow activity through the structure. To date, review of the flow data does not indicate any evidence of an overflow occurring from these locations during the metering period. However, there has been a lack of significant storm activity during the relatively brief flow monitoring period to date and both engineered overflows do produce an overflow when modeled. SSO#140 was discovered on July 20, 2009 and metering is underway to determine the storm return period. SSO#141 was discovered on October 22, 2009 and is located in the same manhole as sealed SSO# 107. A flow meter was installed in this manhole to monitor the closure of SSO#107 and, at the same time monitors activity in SSO#141.

All six SSO structures/cross connections will be included in the corrective action plan for SSO structure removal following construction of the selected alternatives targeting the mitigation of these engineered overflows. Elimination of SSO Structures will be conducted by City forces and completed by the scheduled removal date shown in Section 7.3.

7.2.2 Structural Deficiencies Identified

Proposed Manhole Improvements (Condition Rating Grade 4 & 5):

Table 7.2.2.2 shows a listing of the condition ratings for the manholes inspected within the High Level Sewershed sorted by Region. Table 7.2.2.3 shows all manholes that received a MACP condition rating score of 4 or 5 and are recommended for repairs. Manholes not receiving a condition rating by a manhole inspection crew due to inaccessibility (buried, railroad right-of-way) are given an automatic rating of 4 to ensure they are included in Paragraph 9, Project 1for resolution (See Table 7.3.2). Manholes are further separated by Regions for contract scheduling. Below is the list of basins in each HLSS Region as shown on Map 5.4.1.

Table 7.2.2.1 - Basins in Each HLSS Region

Region	Acronym	Included Metering Basins
Upper Gwynns Run	UGR	HL 34 - 41
West Baltimore	WB	HL 09 -33
High Level Siphon	HLS	HL 08A
Eastern High Level	EHL	HL 06 – 08, TSHL01

Table 7.2.2.2 – Condition Ratings – Manholes by Sewershed Region

		UGR		WB		HLS		EHL	
Overall Condition Rating	**Totals**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
1-Overall Rating	70	3	0.3%	63	1.8%	0	0%	4	1.0%
2-Overall Rating	1570	412	36.7%	988	28.0%	11	47.8%	159	39.8%
3-Overall Rating	2789	568	50.6%	2028	57.5%	5	21.7%	188	47.1%
4-Overall Rating	625	134	11.9%	438	12.4%	7	30.4%	46	11.5%
5-Overall Rating	18	6	0.5%	10	0.3%	0	0%	2	0.5%
MHs Inspected	5072	1123		3527		23		399	

Table 7.2.2.3 - Manhole MACP Condition Ratings 4 & 5

		UGR		WB		HLS		EHL	
Overall Rating	**Totals**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
4-Overall Rating	625	134	11.9%	438	12.4%	7	30.4%	46	11.5%
5-Overall Rating	18	6	0.5%	10	0.3%	0	0%	2	0.5%
MHs Inspected	5072	1123		3527		23		399	

Proposed Sanitary Sewer Improvements:

Table 7.2.2.4 shows the length of the sanitary sewers located within the High Level Sewershed that were ranked as First and/or Second Priority assets requiring repair. All First and Second Priority sewers received condition ratings of 4 or 5 and are recommended for repairs. These sewers are further divided into sub-sewersheds for contract scheduling.

Table 7.2.2.4 - Sanitary Sewers in the High Level Sewershed (Condition Rating 4 & 5)

		UGR		WB		HLS		EHL	
Overall Rating	**Totals**	**LF**	**%**	**LF**	**%**	**LF**	**%**	**LF**	**%**
4/5-Overall Rating	237,255	32,285	14%	189,782	80%	2,382	1%	12,806	5%
Total Region	918,373	242,962		598,468		5,398		71,545	

7.2.3 Proposed High Level Collection System Hydraulic Improvements

The Upper Gwynns Run, West Baltimore, and Eastern High Level Regions require hydraulic improvements to reduce sanitary sewer overflows when conveying the 2-year wet-weather event. Map 5.4.2 shows the location of each recommended improvement and the Alternatives Analysis Report provides further details of the following projects described on a regional basis.

Upper Gwynns Run Interceptor

From the Baseline Analysis and Capacity Assessment Report, there is an estimated volume of 0.76 million gallons of overflows at a 2-year, 24-hour storm event. This is due to the high RDII and limited capacity of this interceptor. We recommend rehabilitation of all of the sewers and manholes in HL37 and 40 (42,896 LF, 172 MH's), building a 15-inch relief sewer in the Liberty Heights area, construction of a 2,400 LF 15-inch relief line from Ridgewood Avenue to Towanda Park and the addition of a 450,000 gallon underground storage tank at Towanda Park to eliminate the 2 year SSO's.

High Level Siphon

Seal the lid of manhole S37CC_034MH to prevent the overflow of approximately 9,000 gallons of sewage during a 2-year, 24-hour storm event. This manhole is the discharge chamber of the High Level Interceptor Siphon. The cost is insignificant and is not included as a line item in any of the cost tables presented in this document.

West Baltimore

From the Baseline Analysis and Capacity Assessment Report, there is an estimated volume of 1.87 million gallons of overflows at a 2-year, 24-hour storm event. The completion of the SC812 relief line (2,400 LF of 30-inch diameter) from Franklin Street to the High Level Interceptor is recommended to mitigate the 2-year overflows.

Eastern High Level Interceptor

The primary goal for this region is to eliminate the recurring SSO's at the Baltimore City Detention Center (BCDC). From the Baseline Analysis and Capacity Assessment Report, there is an estimated volume of 3.1 million gallons of overflows at a 2-year, 24-hour storm event. Heavy cleaning of the HLI to remove 5,781 tons of accumulated sediment is recommended.

7.3 Proposed Improvement Implementation Schedule

An implementation schedule for completion of the proposed SSO elimination and sewer system improvements has been developed as part of this project based on project cost, anticipated project duration, available manpower, and materials. In all cases, projects have been scheduled to minimize public impact and coordinated with other similar projects being conducted throughout the City. The implementation schedule was developed with consideration that all proposed improvements must be completed before January 1, 2016 as stipulated by the CD. The following schedules have been developed providing time to successfully complete the required work.

Sanitary Sewer Overflow Structures:

The newly discovered SSO’s 138, 139, and 140 are in areas recommended for CIPP and manhole rehabilitation. The design and construction for eliminating these SSO’s are included in the Upper Gwynns Run Interceptor RDI/I reduction project. SSO 141 can be eliminated after the completion of paragraph 9, project 3 listed in Table 7.3.4 below.

Recommendations for eliminating the other three overflows #132, 134 & 135, found in the Liberty heights neighborhood of the UGR Region, were submitted to the City ahead of the Alternatives Analysis Report in April 2009 with the intent to take immediate action.

The elimination of all active SSO structures in the High Level Sewershed will be conducted by City forces and are scheduled in Figure 7.3.1. Completion dates correspond to the completion of Paragraph 9 projects designed to eliminate these SSO structures.

Table 7.3.1 – Cross Connection Elimination Schedule

Cross-Connection Location (MH ID)	Connects To	Assigned SSO# (if applicable)	Sched. Removal Date	Removal Complete?	Comments
S15CC_019MH	Roadway Gutter	N/A	3/31/09	Yes	Pipe was a bypass used during construction. Now removed.
S09UU_010MH	Storm Sewer	132	7/1/2011	No	Existing SSO's that could not be eliminated following Paragraph 8 projects. Will be eliminated as part of Paragraph 9 projects.
S11UU_016MH	Storm Sewer	134	7/1/2011	No	
S11UU_008MH	Storm Sewer	135	7/1/2011	No	
S07EE1023MH	Storm Sewer	138	1/1/2013	No	Undocumented cross-connections discovered during Paragraph 9 field inspections.
S11QQ1002MH	Storm Sewer	139	1/1/2013	No	
S07EE1019MH	Storm Sewer	140	1/1/2013	No	
S13GG_042MH	Storm Sewer	141	1/1/2014	No	
S09OO_049MH	Storm Sewer	N/A	11/30/2009	No	
S21KK_010MH	Storm Sewer	N/A	11/30/2009	No	

Manhole Rehabilitation:

The schedule provided in Table 7.3.2 represents a reasonable duration required for the City to select an engineering consultant to prepare the required design documents, advertise the project, select a contractor to complete the required repairs and have the effectiveness of the repairs evaluated.

Table 7.3.2 - Manhole Rehabilitation Implementation Schedule (First and Second Priority)

Paragraph 9 Project	**Project**	**Description**	CD Milestone Dates		
			Advertise Project	**Construction Complete**	**Evaluation Phase Completion**
1	Sanitary Sewer Manhole Rehabilitation	Completion of Manhole Rehabilitation/Replacement Projects Throughout the High Level Sewershed	6/1/2012	12/1/2013	5/31/2014

Sanitary Sewer Rehabilitation:

The schedule provided in Table 7.3.3 represents a reasonable duration required for the City to select an engineering consultant to complete the required design documents, advertise the project, select a contractor to complete the work and have the effectiveness evaluated.

Table 7.3.3 – Sanitary Sewer Rehabilitation Implementation Schedule (First & Second Priority)

Paragraph 9 Project	**Project**	**Description**	CD Milestone Dates		
			Advertise Project (s)	**Construction Complete**	**Evaluation Phase Completion**
2	First Priority Rehabilitation	CIPP and Point Repairs for First Priority	7/1/2012	10/1/2013	4/1/2014
2A	Second Priority Rehabilitation	CIPP, Point Repairs, and Combination CIPP/Point Repairs for Second Priority	8/1/2012	2/1/2014	7/31/2014

Hydraulic Improvements:

The schedule provided in Table 7.3.4 represents a reasonable duration for the City to select an engineering consultant to complete the required design documents, advertise the project, select a contractor, implement the required improvements and evaluate the effectiveness of the repairs.

Table 7.3.4 – Hydraulic Improvement Schedule

Paragraph 9 Project	Project	Description	CD Milestone Dates		
			Advertise Project	**Construction Complete**	**Evaluation Phase Completion**
3	Extend SC812 Sewer	Construct 30” sewer (including railroad crossing). Removes SSO 141	9/1/2012	6/1/2014	12/1/2014
4	High Level Interceptor cleaning	Cleaning of 100” to 144” dia. line from S37CC_034MH to S45EE_005MH. Seal lid of manhole S37CC_034MH	9/15/2012	12/15/2013	6/15/2014
5	UGRI RDII reduction	CIPP of 8” – 15” pipe and MH rehab Intended to remove SSO’s 132, 134, 135, 138, 139 & 140	10/1/2012	1/1/2014	7/1/2014
6	UGR storage tank	450,000 gallon underground storage tank at Towanda Park	1/1/2013	10/1/2014	4/1/2015
7	UGR Relief Line	Construct 15” Sewer from Ridgewood Ave to Towanda Park	2/1/2013	8/1/2014	2/1/2015
8	Liberty Heights Relief Sewer	Construct 15” Relief Sewer from S09UU_007MH to S13UU_008MH	9/15/2010	12/15/2011	6/15/2012
UGRI = Upper Gwynns Run Interceptor UGR = Upper Gwynns Run					

7.4 Estimated Costs of the Proposed Improvement Projects

To characterize expected costs for the collection system improvements necessary in High Level Sewershed, the City completed a review of information compiled from prior City projects for various types of repairs, rehabilitation and replacement of manholes and sanitary sewers. In addition costs were also collected from Means' and a national study of unit costs for a wide variety of repair/replacement options in locations throughout the United States. Once compiled, the information was reviewed, compared and normalized for use in preparing reasonable estimates for the City's sewershed improvements. The City applied various factors to raw unit costs to develop fully-loaded unit costs to represent all of the relevant costs associated with a construction project such as mobilization, bypass pumping, site/paving restoration, and repair of other utilities, which can add significantly to the cost, but are typically required to complete the overall project. These fully loaded unit costs are used in the following estimates. In addition, a factor of 42% is applied to the total construction costs to account for City administrative time, engineering, permitting costs, construction management and inspection services and post award services.

7.4.1 Estimated Improvement Budget

The following section outlines the proposed costs required to implement the First and Second Priority collection system improvements.

Estimated Manhole Rehabilitation Budget:

Table 7.4.1.1 is the estimated 2008 costs required to rehabilitate all First and Second Priority sanitary sewer manholes identified in the High Level collection system. Twenty-one (21) manholes were removed from this summary calculation because their cost is included with the hydraulic recommendations outlined in Table 7.4.1.3.

Table 7.4.1.1 – Estimated Manhole Rehabilitation Improvement Budget

FIRST PRIORITY MANHOLES			
	Unit Cost	Quantity (each)	Cost
Rehabilitation/Replacement	$3,719	13	$48,000
Total MH Rehab:			$48,000
Estimated Design, Const Mngt./Insp. Etc. (42%):			$24,000
Total First Priority MH's:			$80,000
SECOND PRIORITY MANHOLES			
	Unit Cost	Quantity (each)	Cost
Rehabilitation/Replacement	$3,719	609	$2,265,000
Total MH Rehab:			$2,265,000
Estimated Design, Const Mngt./Insp. Etc. (42%):			$928,000
Total Second Priority MH's:			$3,137,000
TOTAL FIRST AND SECOND PRIORITY MANHOLES:			$3,217,000

Estimated Sanitary Sewer Rehabilitation Budget:

Table 7.4.1.2 is the estimated 2008 costs required to rehabilitate all First and Second Priority sanitary sewers identified in the High Level collection system. For each pipe segment, all defects were identified through the CCTV inspection process. Broken pipes and similar severe structural conditions were brought to the attention of the City for immediate repair. Defects that required point repairs were identified and quantified. Point repairs can eliminate RDII sources, correct structural problems or correct alignment and maintenance problems. However, significant RDII reduction is often not achievable through a point repair program. If the number of point repairs exceeded the cost for full length lining of the pipe, then full length lining was recommended. In a few cases, point repairs are required in addition to full length lining since CIPP will not repair all structural defects.

Table 7.4.1.2 – Estimated Sewer Rehabilitation and Replacement Improvement Budget

FIRST PRIORITY SEWERS			
Sewer Size	Unit Cost	CIPP (LF)	Cost
CIPP Lining			
8" Sewer	$45	21,881	$985,000
8+" to 12" Sewer	$64	4,556	$292,000
12+" to 18" Sewer	$87	1,787	$155,000
18+" to 24" Sewer	$124	275	$34,000
24+" to 30" Sewer	$169	268	$45,000
36+" to 42" Sewer	$330	1,032	$341,000
	Total CIPP Lining:	29,799	$1,852,000
		Estimated Design, Const Mngt./Insp. Etc. (42%):	$783,000
		Total First Priority Lining:	$2,630,000
FIRST PRIORITY SEWERS (Cont.)			
Sewer Size	Unit Cost	Point Repair (LF)	Cost
Point Repairs			
8" Sewer	$378	724	$274,000
8+" to 12" Sewer	$378	364	$138,000
12+" to 18" Sewer	$378	256	$97,000
18+" to 24" Sewer	$672	132	$89,000
24+" to 30" Sewer	$841	344	$289,000
30+" to 36" Sewer	$988	216	$213,000
36+" to 42" Sewer	$1,008	400	$403,000
48+" to 54" Sewer	$1,197	484	$579,000
+54" Sewer	$1,260	44	$55,000
	Total Point Repairs:	2,964	$2,137,000
		Estimated Design, Const Mngt./Insp. Etc. (42%):	$884,000
		Total First Priority Point Repair:	$3,035,000

SECOND PRIORITY SEWERS			
Sewer Size	Unit Cost	CIPP (LF)	Cost
CIPP Lining			
8" Sewer	$45	32,754	$1,474,000
8+" to 12" Sewer	$64	2,779	$178,000
12+" to 18" Sewer	$87	987	$86,000
24+" to 30" Sewer	$169	393	$66,000
30+" to 36" Sewer	$300	156	$47,000
36+" to 42" Sewer	$330	20	$7,000
+54" Sewer	$550	128	$70,000
	Total CIPP Lining:	37,217	$1,928,000
		Estimated Design, Const Mngt./Insp. Etc. (42%):	$717,000
		Total Second Priority CIPP Lining:	$2,738,000
SECOND PRIORITY SEWERS (Cont.)			
Sewer Size	Unit Cost	Point Repair (LF)	Cost
Point Repairs			
8" Sewer	$378	1,920	$726,000
8+" to 12" Sewer	$378	228	$86,000
12+" to 18" Sewer	$378	32	$12,000
18+" to 24" Sewer	$672	4	$3,000
24+" to 30" Sewer	$841	16	$13,000
30+" to 36" Sewer	$988	24	$24,000
36+" to 42" Sewer	$1,008	36	$36,000
48+" to 54" Sewer	$1,197	84	$101,000
	Total Point Repairs:	2,344	$1,001,000
		Estimated Design, Const Mngt./Insp. Etc. (42%):	$420,000
		Total Second Priority Point Repair:	$1,421,000

Point Repair and CIPP Lining					
	Point Repair	CIPP	Point Repair (LF)	CIPP (LF)	Cost
8" Sewer (1st Priority)	$378	$45	32	741	$45,000
8" Sewer (2nd Priority)	$378	$45	12	328	$19,000
		Total Point/CIPP Repairs:	44	1,069	$64,000
				Estimated Design, Const Mngt./Insp. Etc. (42%):	$27,000
.				Total Priority Point/CIPP Repair:	$91,000
				TOTAL ESTIMATED PRIORITY REPAIRS:	$4,250,000
				TOTAL ESTIMATED FIRST & SECOND PRIORITY SEWER REPAIRS:	$9,980,000

Estimated Hydraulic Improvement Budget:

Table 7.4.1.3 contains the estimated 2008 costs required to complete the hydraulic improvements for each sub-sewershed in the High Level Sewershed.

Table 7.4.1.3 – Estimated Hydraulic Improvement Budget

Diameter	Rehabilitation Method	Unit Cost	Quantity	Unit	Cost
Upper Gwynns Run Interceptor Region					
8 Inch Sewer	CIPP	$45	39,215	LF	$1,765,000
10 inch sewer	CIPP	$64	3,680	LF	$236,000
15 inch sewer	Relief Line	$585	5,200	LF	$3,042,000
Manholes	Rehab and New	$3,719	194	Each	$721,000
Underground storage tank	New Construction	$6	450,000	Gal	$2,700,000
			Subtotal:		$8,464,000
Estimated Design, Const Mngt./Insp. Etc. (42%):					$3,555,000
TOTAL:					$12,019,000
West Baltimore Region					
SC 812 (30 inch sewer)	New Construction	$1,440	2400	LF	$3,456,000
Manholes	New Construction	$3,719	6	Each	$22,000
			Subtotal:		$3,478,000
Estimated Design, Const Mngt./Insp. Etc. (42%):					$1,461,000
TOTAL:					$4,939,000
Eastern High Level Interceptor Region					
80" to 100" pipe	Heavy Cleaning	$500	5781	Tons	$2,891,000
			Subtotal:		$2,891,000
Estimated Design, Const Mngt./Insp. Etc. (42%):					$1,214,000
TOTAL:					$4,105,000
TOTAL ESTIMATED HYDRAULIC IMPROVEMENT COSTS:					**$21,063,000**

The combined total costs associated with completing the First and Second Priority manhole repairs, sewer system repairs, and the hydraulic improvements to the conveyance system in the High Level Sewershed are estimated to be approximately **$34,262,000**.

7.5 Sewershed Re-Inspection Program

Per the requirements of the CD, the City's High Level Sewershed's collection system needs to be re-inspected by January 1, 2016. The following sections outline the requirements of the re-inspection program and provide a general schedule to complete this work.

7.5.1 Re-Inspection Prioritization Scheme

The City's condition and criticality protocol provides a framework for a continuous rehabilitation strategy of all collection system components based on both criticality (consequence of failure) and condition (probability of failure). Assets whose failure can have large impacts on the community and the environment and whose condition is the poorest will receive a higher criticality and condition rating and will receive attention in a more timely manner. Assets that receive a lower criticality and condition rating will receive some level of continued monitoring as recommended herein but no immediate action or rehabilitation. Refer to Section 7.1 Decision Making Criteria for details. The following sections detail the requirements of future inspection programs.

7.5.2 CCTV and Manhole Inspections

The implementation schedule provided includes provisions for the re-inspection of each of the collection system components by January 1, 2016. The proposed re-inspection schedule includes provisions for, but is not necessarily limited to, a prioritization scheme for further inspection of collection system components based on the following criteria:

1) Prior identification of system defects, prior NASSCO PACP or MACP rating codes, grease blockages, root intrusion or system complaint data.
2) Prior criticality and condition ratings.
3) Expected life cycle of system components.
4) Estimated rate of existing or potential inflow and/or infiltration.
5) Scheduled rehabilitation or other corrective action of a system component; and the predetermined re-inspection frequency of a collection system component.

Based on the results of the inspections completed during this sewershed study, the re-inspection schedule identified by the CD and the rehabilitation work which has been detailed as part of this plan, it is recommended that all PACP condition grade 1 and 2 sewers in the High Level Sewershed be re-inspected in a 5 to 10 year range. All PACP condition grade 3 sewers should be re-inspected in 2 to 3 years to reassess their condition and assign appropriate repairs as needed.

The implementation schedule for re-inspection of these sewershed system components is outlined in Table 7.5.2.1:

Table 7.5.2.1 - Sewershed Re-Inspection Implementation Schedule

Task	Duration (Yrs.)	Start Date	End Date
Manhole Inspections	3 1/2	1/1/2011	6/30/2014
Analysis and Report	1 1/2	7/1/2014	12/31/2015
Sewer Inspections	3 1/2	1/1/2011	6/30/2014
Analysis and Report	1 1/2	7/1/2014	12/31/2015

Based on the condition of the assets observed during this study, manholes and sewers that received ratings of 4 or 5 were recommended for inclusion on the First and Second Priority corrective action plan. Once rehabilitated, these manholes and sewers should be placed on a “Low Priority” inspection program with regular inspections occurring once every 5 to 10 years.

The manholes and sewers that received condition ratings of 3 were classified as requiring “Frequent Assessment” under the condition and criticality rating system should be inspected on regular 2-3 year inspection intervals to insure the continuity of the collection system.

Manholes and sewer segments that received a rating of 2 (identified as requiring “Regular Monitoring”) should be inspected every 3-5 years. Based on the results of those inspections, any manholes and/or sewers that have continued to deteriorate to a point that requires repair should be repaired on an as-needed basis to address specific problems or deficiencies that have occurred.

7.6 Future Data Collection and Evaluation Services

As required by the CD, under Paragraph 9-C-xii, the City will be required to implement several continuous data collection programs in order to assess the effectiveness of the rehabilitation programs and other O&M enhancement efforts within the sewershed. These programs will be comprehensive, system-wide initiatives that will include a long-term flow monitoring plan, a sewer cleaning program, CCTV and manhole inspection programs and root control and grease control programs. These are discussed in more detail in the following sections.

7.6.1 Long-Term Flow Monitoring Plan

In 2006 the City of Baltimore implemented a comprehensive flow monitoring program for the purpose of evaluating the severity of infiltration and inflow and for calibration of the hydraulic model. This comprehensive program consisted of a network of about 350 flow meters, 20 rain gauges, 33 groundwater monitoring stations and extended for a period of one year from May 2006 through May 2007. In May 2007, the network was reduced to about 100 flow meters that were placed at key points and junctions in the collection system for the purpose of long term assessment and continuous calibration of the hydraulic model. All 20 rain gauges remained in operation. The City plans to continue monitoring the flows in order to assess the effectiveness of the on-going and future rehabilitation and O&M enhancement programs.

7.6.2 Sewer Cleaning Program

The effectiveness of a sewer conveyance system is largely dependent on its ability to convey the flows generated within the sewer basin without surcharging the system to a point where overflows occur. As part of the sewer inspection program completed for this study, all sewers that were inspected were also lightly cleaned. The intent of the cleaning was to clean the sewer so the inspections could identify defects that otherwise would not be visible during the inspection and to remove debris from the sewer to restore the sewer to at least 95% of its original carrying capacity. The only exceptions to cleaning were the large diameter High Level and Gwynns Run Interceptors. Sonar inspections were utilized in these areas.

Heavy cleaning was authorized where needed to allow for internal inspection. Heavy cleaning involved root cutting, grease removal and/or additional passes of the hydro-cleaning equipment to remove heavy accumulations of sediment and debris. All debris was removed from the sewers and disposed of at an approved disposal site.

If heavy cleaning was not successful, the sewers were considered “exceptions” and marked for specialty cleaning at a later date.

Based on the cleaning work completed during this project and observations from the inspection work completed, it is recommended that sewers which contain heavy accumulations of grease, debris and/or roots, large interceptor sewers, sewer siphons, and sewers with velocities less than 3 feet per second (fps) should be cleaned on regular 5 year intervals. These cleaning operations should be closely coordinated with the sewer re-inspection program, which needs to be completed by January 1, 2016 and prioritized based on condition and criticality rating factors that were determined during the inspections described in Section 7.1. Under normal operating conditions, the remaining sewers should not require additional cleaning between the 5 to 10 year Low Priority sewer inspection cycles.

7.6.3 CCTV and Manhole Inspection Programs

The City also intends to implement continuous citywide CCTV and manhole inspection programs following the completion of the CD sewershed studies, which are scheduled to be completed between January 2009 and July 2010. These programs will be aimed at re-inspecting all gravity sewers 8-inches and larger in diameter, force mains, pumping stations, manholes and other sewer structures by January 1, 2016. The planned re-inspection activities will be prioritized based on each segment's condition and criticality ratings that were derived during the sewershed inspections described in Section 7.1 of this report.

7.6.4 Root Control Program

In 2004, the City began monitoring the impacts of root infestation in their collection system by tracking and geocoding customer calls related to root problems in the sewer. In 2006, the City identified an area in the Herring Run Sewershed having severe root intrusion problems (approximately 1,500 acres, 230,000 linear feet of pipe). The City proceeded to implement a root control chemical application pilot project in this area in 2007, which included the treatment of approximately 150 house laterals and service connections. The pilot project yielded promising results. The City is therefore expanding the Root Control Program (RCP) into other areas of the collection system with documented root intrusion problems. A recent evaluation of customer calls in 2007 identified two additional areas with severe root infestation (see Figure 7.6.4). One area is located in the Western Run section of the Jones Falls Sewershed, and the other in the Maidens Choice section of the Gwynns Falls Sewershed. There are no severe root infestation areas within the High Level Sewershed.

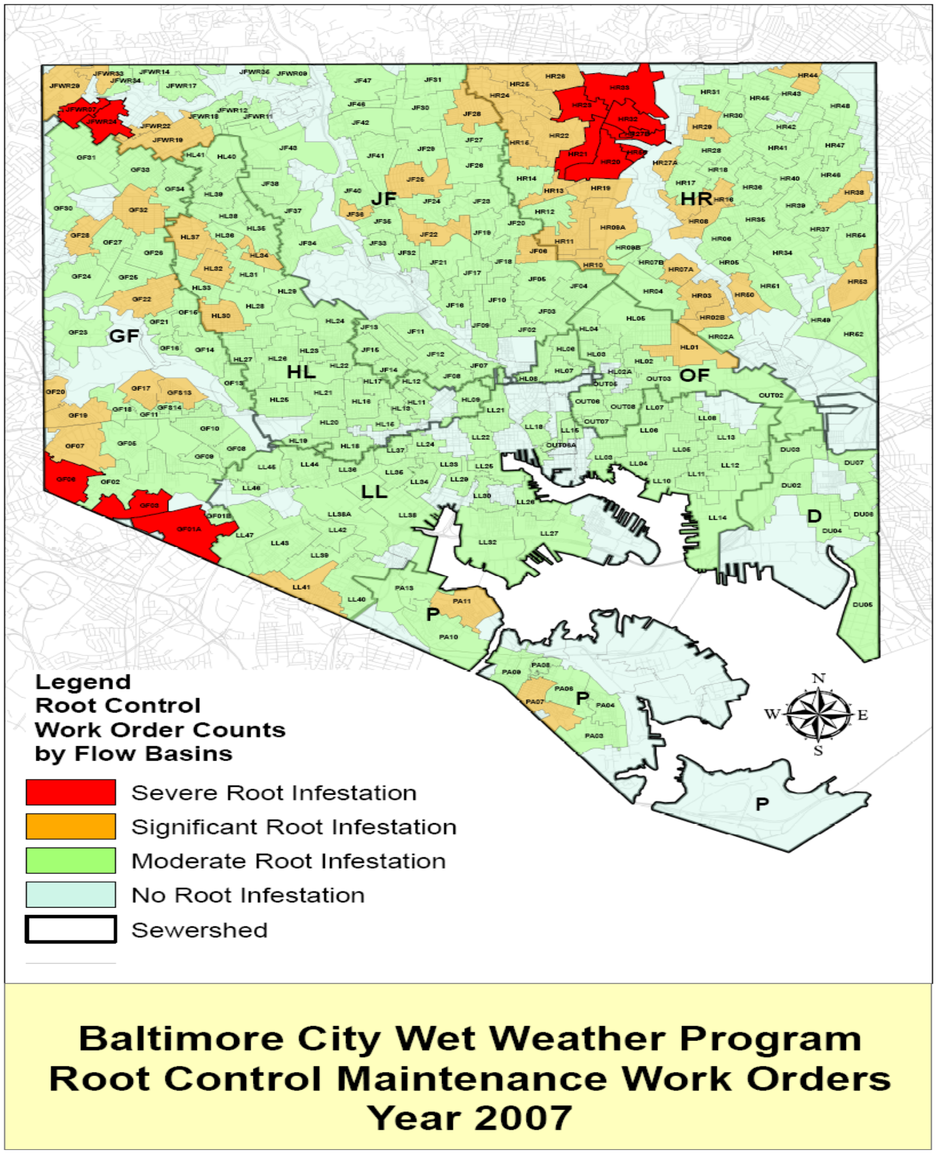


Figure 7.6.4-Root Control Analysis

To evaluate the effectiveness of the on-going root control program, other sources of information, such as CCTV and manhole inspections, will be used to validate and direct the root control efforts. The goal of the on-going RCP is to treat all areas of the collection system experiencing root infestation once every three to five years. The effectiveness of the RCP will be assessed by continued monitoring of the areas and continuous evaluation of customer complaint calls within these areas on a six month review basis.

7.6.5 Fats, Oils, and Grease Control Programs

Similar to root infestation in the sewer system, the City also began assessing the impacts of Fats, Oils and Grease (FOG) in the collection system in 2004. The City geocoded and mapped all customer complaint calls related to FOG and identified five sections of the collection system where severe problems exist. Not surprisingly, these sections serve areas with numerous restaurants and/or food establishments, namely Reisterstown Road corridor, and the upper reaches of the High Level Sewershed, which have numerous restaurants and a major mall with a food court. The City proceeded to outfit two of its newest sewer vac-trucks with de-greasing equipment and began treating the targeted areas in 2006. These areas are currently on a regular cleaning schedule and are addressed twice a year for grease. Baltimore will continue to evaluate customer complaint calls and utilize CCTV and manhole inspection data in order to assess and guide future activities of the FOG Program.